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A COMPARATIVE STUDY OF THE MOSAIC DISEASES OF CUCUMBER, TOMATO, AND PHYSALIS

M. N. WALKER[1]

INTRODUCTION

The results of cross-inoculation experiments with the mosaic diseases occurring on various plants have shown that many of these diseases affect a wide range of hosts. The work of Doolittle (11, 12) and of Elmer (15) has shown that the mosaic occurring on a given host may be transmitted to plants of widely separated families and would seem to indicate that a number of mosaic diseases may have the same causal agency. At the same time, Jagger (17), working on the mosaic disease of cucumber, has described what he believes to be two distinct mosaic diseases of this host. Allard (3) states that there are at least two distinct mosaic diseases in the genus *Nicotiana*, and Schultz and Folsom (19) have described and named seven different virus diseases in the genus *Solanum*. We have, therefore, two lines of evidence, one indicating an extended host range for individual mosaic diseases, and the other indicating the existence of a number of distinct types of mosaics on a single host species. From the latter possibility the question arises as to whether, for instance, we may consider the mosaic disease on cucumbers infected from mosaic milkweeds as cucumber mosaic, or as milkweed mosaic on the cucumber. If we follow the latter system, the whole field of mosaic investigations becomes tremendously complicated, since it is obviously impossible to determine the original source of a single mosaic disease.

Where the symptoms resulting from successful cross-inoculations are identical, it appears easier to accept the theory of a single mosaic disease which is capable of infecting a large number of hosts than that of a number of distinct mosaic diseases each with the same extended host range. From the accumulated evidence of successful cross-inoculations, the number of distinct mosaic diseases would seem to be less than is sometimes stated or

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implied, but in some cases this evidence alone seems hardly sufficient to fully establish a single causal agency for the mosaics occurring on the various hosts.

A comparison of the results of experiments by Allard and other workers on the properties of the virus of tobacco mosaic with those obtained by Doolittle in work on the virus of cucumber mosaic shows a decided difference in the reactions of these viruses to certain vital tests. These tests seem conclusive in showing two distinct causal principles for the two diseases. Doolittle (12), however, has shown that, by using the pepper as an intermediate or bridging host, it is possible to make successful cross-inoculations from tobacco to cucumber and vice versa; Elmer (15) reports direct infection of tobacco with cucumber mosaic. These facts suggested that a comparative study of these apparently differing viruses, in connection with cross-inoculation studies, might prove of value in interpreting the results of the cross-inoculations mentioned. Two possibilities arose: first, that, were the differences in the viruses of the two diseases actual, the virus in the juices of plants of one species infected from plants of another species would show the properties of the virus of the infecting host. That is, should cucumber plants be inoculated from mosaic tobacco plants, the properties of the extract from these mosaic cucumber plants would be the same as those of the extract from mosaic tobacco plants, and would indicate that the diseases of the two hosts were distinct and caused by different agencies. Secondly, that, were the differences only apparent and dependent on the environments within the different hosts, such changes would occur in the virus of one host, when transferred to another, as to make it appear identical with the virus of the second host. In such a case, the extract from cucumber plants inoculated from mosaic tobacco would react in the same manner to different tests as the extract from cucumber plants infected from other mosaic cucumbers. In either case it appeared that the results of such tests would give more definite evidence as to the identity or dissimilarity of the two diseases. Representative mosaic hosts from the Cucurbitaceae and the Solanaceae, together with a suitable intermediate host, were selected for this work. Since the mosaic disease of tomato is apparently identical with tobacco mosaic, and because the properties of the virus of tomato have been little studied, this plant was used as the representative of the Solanaceae. In recent work by the writer (20), the cultivated ground cherry (*Physalis pubescens*) has been shown to be an intermediate host in cross-inoculations from the tomato to the cucumber; it was, therefore, chosen as the intermediate host. The cucumber was used as the third host plant. It was planned to determine first the reactions of the infective principle of the mosaic disease of each of these hosts to certain tests, and then to determine the changes that might occur in the virus from one host inoculated with the

virus of another plant. The difficulty lay in deciding on what might be taken as the typical virus of any one plant, since, on account of the general transmissibility of many of the mosaic diseases, it is impossible to know positively the original source of infection of a single mosaic disease. The disease on tomato, for instance, might have originally come from tobacco, or any other solanaceous host; consequently the infective principle in the extracted juices of a mosaic plant cannot be called the virus of the disease of that plant in the sense that it is specific for that particular host. Specific in this sense is more or less inaccurate, for apparently all mosaic diseases may be inoculated to hosts other than that on which the disease occurs, but the term is used here to denote a virus that might be considered typical or usual on a single species of host. As a means of obviating this difficulty, it was assumed that plants naturally infected with mosaic would be as nearly typical as any that might be obtained; and, following this assumption, stocks of mosaic plants of the species used in the experiments were obtained by inoculations from naturally infected tomatoes, ground cherries, and cucumbers; and all the extracts used in the work came from these stocks. It seemed best for the sake of accuracy to avoid as far as possible the use of the term virus, which has often been used for the expressed juices of mosaic plants, and to substitute the term extract, which can be qualified by stating the immediate source of infection on the plants from which the extract is taken. The use of some such general term was especially necessary in the case of extracts from plants of the same species inoculated from two or more different sources. For example, it is obvious that the extracts from tomato plants infected from tomatoes and from ground cherries could not both be called the virus of tomato mosaic; the latter would have to be called the virus of ground cherry mosaic extracted from tomatoes. The term virus, therefore, is only used in the general sense of the infective principle or causal agent, and in quotations from other workers.

For the purposes of comparison, tests were made with the extracts from different host plants to determine: (a) the longevity of the infective agent; (b) its resistance to drying; (c) its resistance to heat; (d) its resistance to the higher percentages of alcohol; (e) its resistance to dilution; and (f) its ability to pass through the finer-pored filters. Various things interfered to prevent the completion of the work in the desired detail, and after some preliminary experiments the last three points were found to give results so nearly identical in the case of the juices of all three hosts that they were of little value as bases of comparison; consequently they were not followed as closely throughout the work as in the beginning.

Since the tests selected were primarily to furnish comparisons rather than to determine the exact properties of the virus in the different extracts, the absolute properties have in no case been accurately determined. When

one extract, for instance, showed a decided difference from another, that was considered sufficient for the present purposes, and no attempt was made to follow the tests to their exact endpoints. In the light of results set forth in the succeeding pages, it is a question whether such properties are of great value in determining the fundamental nature of the infective entity of the mosaic diseases, for it is shown that it is possible to change radically the properties of a particular virus by transferring it to another host. Thus, such tests represent only the reaction of the virus when combined with the extracted juices of a particular host and are not necessarily indicative of the fundamental nature of the infective principle.

REVIEW OF STUDIES ON THE PROPERTIES OF THE INFECTIVE PRINCIPLE IN THE EXTRACT FROM MOSAIC TOBACCO PLANTS

The work that has been done on the properties of the infective principle in the extracted juices of mosaic tobacco plants represents the greater part of the virus studies that have been made with the mosaic diseases. They have served, therefore, as a source of suggestion in outlining comparative tests for the diseases studied here. For this reason it seemed best to review the work on the virus of tobacco mosaic and to make incidental comparison of this virus with those specifically studied here. The literature cited includes only those papers that have direct bearing on this phase of mosaic disease investigations. The most thorough and extensive work with the tobacco virus has been done by Allard, and his work is the basis of the major portion of the summary of the properties of the tobacco virus. The work of other men is cited under individual headings of the summary when their results have helped to determine the particular property there mentioned.

Resistance to ageing. The virus of the mosaic disease of tobacco has been found by all workers (1, 4, 5, 8, 9) to remain infective for a considerable period of time after extraction from the plant. Both with and without preservatives the extract from mosaic tobacco plants has been shown to remain infective for as long as three years.

Resistance to drying. Several workers (1, 4, 5, 8, 9) have noted the resistance of the virus of tobacco mosaic to prolonged periods of drying at air temperatures. Both air-dried leaves and the residue from evaporation of the extracted juice have proved infective when taken up in water and inoculated into young plants two years later.

Thermal death point. A considerable range of temperatures has been suggested by different writers (1, 4, 5, 8, 9, 14) in naming a thermal death point for the virus of tobacco mosaic. No two men have used the same time for treating the virus at a given temperature, and this fact makes the selec-

tion of a thermal death point difficult. The range of temperature is from 80° to 100° C., and it has been found that the tobacco virus from different sources varies somewhat in resistance to heat. The most probable thermal death point seems to lie between 85° and 90° C. for a 10 minute period, corresponding to the time used for heat treatment in the present work.

Resistance to treatment with alcohol. In the determination of the resistance of the tobacco virus to different percentages of alcohol, the time element makes definite statements difficult. Allard (4) has shown the virus to be capable of withstanding percentages of alcohol up to 50 per cent for several days; higher percentages rendered the virus inert in varying lengths of time. In any case, the virus shows a striking resistance to percentages of alcohol which are fatal to bacteria in the vegetative state; and, even with the higher percentages, some time is necessary to effect an attenuation of the virus.

The effect of dilution. Allard (2) has shown that dilution of the virus of tobacco mosaic at the rate of one part to one thousand parts of water does not attenuate the virus; although higher dilutions reduce its infective power.

Ability of the infective principle to pass filters. It has been shown by several different workers (1, 4, 5, 8, 9, 10, 13) that the virus of tobacco mosaic is capable of passing through Berkfeld and Chamberland filters without losing its infective powers. Certain filters have been found capable of retaining the infective particles (parchment shells, layers of agar and powdered talc), and, by using a graded series of filters, Duggar (13) has estimated the size of the infective particles of the mosaic disease of tobacco to be in the neighborhood of 30 millimicrons.

STUDIES ON THE PROPERTIES OF THE INFECTIVE PRINCIPLE IN THE EXTRACT FROM MOSAIC TOMATO PLANTS

Little work has been done on the properties of the virus of tomato mosaic, only one paper mentioning such work. Westerdijk (22) reports that the thermal death point for the virus lies between 50° and 100° C., and that it is quite resistant to drying. Since so little work has been done with the virus of tomato mosaic, it was necessary to make a study of the virus before comparing it with viruses from tomato plants inoculated from different sources. The study was limited to the six points selected as bases for comparison. The extracts for all these experiments were taken from mosaic plants infected from the same source, a stock of mosaic plants developed from tomato plants found naturally infected in the greenhouse, and were obtained by first grinding the plants in a food-chopper and then squeezing the juice from the pulp so obtained through a piece of cloth. The variety of tomato used in all the present experiments was Bonny Best. When used

for inoculations the plants were stocky, deep green in color, and averaged about six inches in height.

Resistance to ageing. It was found that the extract from mosaic tomato plants does not lose its infective power after a considerable period of time. In the experiments, extracts were kept for varying lengths of time in small, stoppered flasks, with no effort made to prevent fermentation. They were then used to inoculate healthy young tomato plants. Inoculations were made by inserting the inoculum in two stem incisions, the lower of which was usually in the wound made by removing a leaf, and by pricking the inoculum into the younger leaves in many places. Inoculations with the extract kept 138 days produced infection in a single case. The results of this experiment, and others, are shown in table 1.

TABLE 1.—*The resistance to ageing of the infective principle in the extract from mosaic tomato plants*

Date inoculated 1924	Age of virus in days	No. plants inoculated	No. plants diseased	Date observed, 1924
April 17	38	5	2	April 28
April 21	4	8	7	May 12
April 23	6	8	6	May 12
April 17	38	5	2	April 28
July 25	138	6	1	August 3

Resistance to drying. The work of Westerdijk (22) on the resistance of the tomato virus to drying was sufficient to show a difference from the virus of cucumber. Although the work was not extensive, it showed that the virus was somewhat resistant to drying, which, were it even in the slightest degree, would render it unlike the cucumber virus, which has been shown by Doolittle (11) to be unable to withstand drying.

The work of the writer also shows that the infective principle in the extract from mosaic tomato plants is capable of withstanding drying, although the limit of this endurance was not determined. It is probable, however, that its resistance is the same as that of tobacco, but, as one experiment showed a resistance of sufficient duration to distinguish it in this point from the extract from mosaic cucumber plants, this detail was omitted. In this experiment, 3 out of 6, and 2 out of 5 plants became infected when inoculated with material dried for 4 and 30 days, respectively. In a series of controls in which the fresh juice served as inoculum, 4 out of 5 plants became infected.

Resistance to heating. In experiments on the resistance of the viruses of the various mosaic diseases to heating, the same method is used as that described by Kendrick (18) for thermal death point work. Test tubes containing 10 cc. of the juices expressed from mosaic plants were suspended in water brought to the desired temperature and allowed to remain for 10 minutes. They were then removed and immediately suspended in cold water to cool. The juices then were used to inoculate young plants, using the juice heated to the highest temperature first, and so on down the entire series to the control inoculations made with the unheated juice.

Because of the wide range of temperatures indicated in Westerdijk's paper (22), a more thorough study of this question was undertaken. The results in table 2 show that the thermal death point of the tomato virus lies within a narrower range than that suggested by Westerdijk. The virus became innocuous in all experiments when heated to temperatures between 85° and 90° C., with the exception of one series in which one plant became infected after treatment of the virus at 95° C.

The inability to find a definite thermal point for the infective principle in the extracts from mosaic plants means little when it is considered that one is not working with the virus or infective principle alone, but with the variable medium of the plant juices as well. The possibility of there being decided differences in the infective power of the virus is shown in previous experiments by the writer (20, 21), who has found an apparent decrease in the virulence of the extract from mosaic plants at different times of the year. It is impossible to say what part of this may be attributed to changes in the actual infective principle, and what part to changes in the composition of the plant juices at different times, but in any case this work indicates that it is difficult to determine the definite thermal relationship or any other property of something hidden in a fluid extract, the composition of which varies with the source and the season. No definite thermal death point can be ascertained until the infective entity is isolated from the many other substances in the extracts from mosaic plants which apparently exert such a marked influence on the behavior of the virus.

Resistance to treatment with alcohol. In testing the effect of treatment with alcohol on the extracts from mosaic plants, small quantities of the extracted juices were brought to various percentages of alcohol by the addition of absolute alcohol, and allowed to stand for one hour. In all treatments with alcohol a light flocculent precipitate occurred which was separated from the supernatant liquid by centrifuging. This precipitate then was taken up in a small quantity of water and used to inoculate young, healthy plants. No inoculations were made with the green supernatant alcoholic solution.

TABLE 2.—*The effect of temperature on the infective principle in the extract from mosaic tomato plants*

Date inoculated, 1924	Temperature in degrees C. (constant for 10 min.)	No. plants inoculated	No. plants diseased	Date observed, 1924
Feb. 14	65	4	0	March 3
do	70	4	2	do
do	75	4	0	do
do	80	4	0	do
do	85	4	2	do
do	90	4	0	do
do	Unheated extract (Control)	4	2	do
March 3	65	5	3	March 19
do	70	5	4	do
do	75	5	3	do
do	80	5	2	do
do	85	5	1	do
do	90	5	0	do
do	95	5	0	do
do	100	5	0	do
do	Unheated extract (Control)	5	1	do
March 10	65	4	4	March 19
do	70	4	4	do
do	75	4	3	do
do	80	4	4	do
do	85	4	2	do
do	90	4	0	do
do	95	4	0	do
do	Unheated extract (Control)	8	7	do
March 21	65	4	4	April 8
do	70	4	3	do
do	75	4	2	do
do	80	4	2	do
do	85	4	0	do
do	90	4	0	do
do	95	4	0	do
do	100	4	0	do
do	Unheated extract (Control)	8	6	do
March 27	75	6	2	April 14
do	80	6	5	do
do	85	6	4	do
do	90	6	1	do
do	95	6	1	do
do	Unheated extract (Control)	12	10	do

TABLE 3.—*The effect of alcohol on the infective principle in the extract from mosaic tomato plants*

Date inoculated, 1924	Per cent alcohol used	Time	No. plants inoculated	No. plants diseased	Date observed, 1924
April 17	33	1 hr.	5	3	April 28
do	75	do	5	4	do
do	80	do	5	1	do
do	85	do	5	2	do
do	95	do	5	1	do
April 25	80	do	8	8	May 10
do	85	do	8	7	do
do	90	do	9	8	do
do	95	do	8	8	do
do	Untreated extract (Control)	do	8	8	do

In the experiments of this nature with the expressed juices from mosaic tomato plants, it was shown that there is a marked resistance to alcohol of the infective principle in these juices. Infection followed inoculation with the precipitate from treatment with all percentages of alcohol used up to the highest, 95 per cent. The results of inoculations with the precipitate from different percentages of alcohol are given in table 3.

The effect of dilution. A few experiments were made with the extract from mosaic tomato plants to determine to what extent it might be diluted

TABLE 4.—*The effect of dilution on the infective principle in the extract from mosaic tomato plants*

Date inoculated, 1924	Dilution	No. plants inoculated	No. plants diseased	Date observed, 1924
April 17	1:20	5	5	April 28
do	1:200	5	4	do
do	1:1,000	5	0	do
do	1:2,000	5	1	do
do	1:20,000	5	0	do
do	Undiluted extract (Control)	5	2	do
April 28	1:100	8	7	May 10
do	1:1,000	8	4	do
do	1:10,000	8	2	do
do	Undiluted extract (Control)	8	8	do

before becoming attenuate. It was found that the infective power of the virus was not reduced greatly until after a thousand parts of water had been added.

Dilution experiments furnished no opportunity for comparing the viruses studied in the present work, for all experiments of this sort gave approximately the same results. Of the six points used as bases of comparison, this one is probably the most indefinite and is subject to greater variation than any of the other points. The results of dilution experiments with the extract from mosaic tomatoes appear in table 4.

Ability of the infective principle to pass filters. It has been impossible to contrast the infective principles from various mosaic diseases by the results from filtration experiments, because the results of all tests were so nearly alike. The greater portion of the present experiments have been made with Berkfeld filters of three grades: coarse, medium, and fine, which are lettered V, N, and W respectively, and which were of the 1″ x 6″ size. A few experiments also have been made with Chamberland filters, grades F, coarse, and B, fine, but results have been no more conclusive than those obtained with Berkfeld filters. The fact that the filtrates from Berkfeld filters were all infective, and the fact that the filtrates from Chamberland filters gave such low percentages of infection, precluded the use of these filters for routine comparisons of the viruses.

The results of filtrations with the extract from mosaic tomato plants show that the infective principle in it is capable of passing through all grades of Berkfeld filters with little loss of infective power. These results are set forth in table 5.

TABLE 5.—*The results of inoculating healthy tomato plants with the filtered extract from mosaic tomato plants*

Date inoculated 1924	Filter used	No plants inoculated	No. plants diseased	Date observed, 1924
March 10	Berkfeld W	8	4	March 24
April 14	do W	16	8	April 26
do	do N	8	7	do
do	do V	8	6	do
do	Unfiltered extract (Control)	8	8	do
April 16	Berkfeld W	8	7	April 28
do	do N	9	9	do
do	do V	8	7	do
do	Unfiltered extract (Control)	8	8	do

STUDIES ON THE PROPERTIES OF THE INFECTIVE PRINCIPLE IN THE EXTRACT FROM MOSAIC GROUND CHERRY PLANTS

The preliminary tests with the extracts from mosaic ground cherry plants showed a marked similarity to the tests on tomato extract. In some cases the results were not so extensive as those with the tomato, but the results indicate that the infective principles of these diseases behave in the same manner.

Resistance to ageing. The infective properties of the extract from mosaic ground cherry plants is apparently little impaired by being held for long periods of time without preservatives. The ultimate range of time necessary to effect attenuation in the virus has not been determined, but it was found infectious by means of inoculations to healthy young ground cherry plants after 69 days. Three tests were made in each of which 6 plants were inoculated with extracts 13, 28, and 69 days old. In each of the first two experiments, 4 plants became infected; and in the third, 2.

Resistance to drying. In a limited number of experiments it was shown that the infective principle in the extract from mosaic ground cherry plants resists drying to a degree comparable with that of the infective principle in the extract from mosaic tomato plants. Two series of experiments have shown that the dried extracts remain infectious for at least 23 days.

Resistance to heating. In experiments in which the extract from mosaic ground cherries was heated to different temperatures and then used to inoculate young plants, it was shown that the infective principle, or virus, in the extract is capable of withstanding heating to the same degree as the viruses of tomato and of tobacco mosaic. The virus remained infective after treatment for ten minutes at 85° C. but became innocuous a little above this temperature. Table 6 presents the results of these experiments.

TABLE 6.—*The effect of different temperatures on the infective principle in the extract from mosaic ground cherry plants*

Date inoculated	Temperature in degrees C. (constant for 10 min.)	No. plants inoculated	No. plants diseased	Date observed
May 22, 1924	65	5	5	June 1, 1924
do	70	5	5	do
do	75	5	5	do
do	80	5	4	do
do	85	5	2	do
do	90	5	0	do
do	95	5	0	do
do	Unheated extract (Control)	5	5	do

Resistance to treatment with alcohol. Experiments with the extract from mosaic ground cherries showed that the infective principle in the extract behaves in the same manner toward high percentages of alcohol as those from mosaic tomato and mosaic tobacco plants. When the virus was treated with 95 per cent alcohol for one hour, infection occurred in 3 out of 8 inoculated plants and similar results were secured with 50, 60, 70, and 80 per cent alcohols.

The effect of dilution. Tests on the relation of the infective principle from mosaic ground cherry plants to dilution show that it remains infective in as high dilutions as the viruses of tobacco and tomato mosaic. It was found in a single series of inoculations with the dilutions 1:10, 1:100, 1:1,000, and 1:10,000 that 4 out of 5, 2 out of 5, 3 out of 5, and 1 out of 5 plants, respectively, became infected. In the control inoculations with the undiluted extract, 3 out of 5 plants became infected.

Ability of the infective principle to pass filters. The infective principle in the extract from mosaic ground cherry plants appears to lose little of its infective nature after passing through the various grades of Berkfeld filters. Inoculations with the filtrate from all grades of Berkfeld filters, from coarse to fine, resulted in about the same percentage of infection; this is shown in table 7.

TABLE 7.—*Results of inoculating healthy ground cherry plants with the filtered extract from mosaic ground cherry plants*

Date inoculated, 1924	Filter used	No. plants inoculated	No. plants diseased	Date observed, 1924
April 26	Berkfeld W	8	5	May 12
do	do N	8	5	do
do	do V	8	6	do
May 28	do W	5	2	June 14
do	do N	5	2	do
do	do V	5	2	do
do	Unfiltered extract (Control)	5	4	do

PROPERTIES OF THE INFECTIVE PRINCIPLE IN THE EXTRACT FROM MOSAIC CUCUMBER PLANTS

The rapid loss of the pathogenicity of the extract from mosaic cucumber plants after the juices are expressed has forced the writer to fall back, to a large extent, on other work for positive data concerning the properties of the infective principle in the extract. All the experiments conducted by the writer with the extract from mosaic cucumber have given unsatis-

factory results. The small amount of infection in some experiments, and the total lack of infection in others, has allowed only conclusions concerning the short-lived nature of the virus, which did not permit the handling necessary for the different tests.

Doolittle (11), to whose paper the writer is indebted for positive data on the properties of the infective principle in the extract from mosaic cucumber, reports a similar difficulty in much of his work with this extract.

Resistance to ageing. Doolittle reports that: "Repeated tests have shown the juices of mosaic plants of cucumber, squash, pumpkin, muskmelon, and *Micrampelis lobata* are never infectious for more than three to five days and in most cases lose their virulence within 24 to 48 hours." Preservatives and low temperatures were found to prolong in no way the period of virulence of the infective principle from these plants.

The results of the writer's experiments, tabulated in table 8, are in accord with those of Doolittle's experiments, and show the inability of the infective principle in the extract from mosaic cucumbers to withstand ageing.

TABLE 8.—*The resistance to ageing of the infective principle in the extract from mosaic cucumbers*

Date inoculated, 1924	Age of virus	No. plants inoculated	No. plants diseased	Date observed, 1924
July 6	1 hour (Control)	8	2	July 16
July 19	do	6	2	Aug. 1
July 7	24 hours	4	1	July 16
Aug. 2	do	6	0	Aug. 11
July 8	48 hours	4	0	July 16
March 10	6 days	8	0	March 19

Resistance to drying. In the case of experiments on the resistance of the virus to drying, Doolittle states that: "As the juices of mosaic plants rapidly lose their power of infection with age, it would be expected that drying would also remove this infective character. This has been the case with the tissues of mosaic cucumber plants." In no case did Doolittle find infection to follow inoculation either after drying down the virus at room temperatures and then taking it up in water, or after drying down leaves and later pulverizing them in water. Results of a single experiment by the writer also showed that the extract from mosaic cucumber plants will not withstand drying for 24 hours. From the results in connection with Doolittle's work, and the results set forth later, on the effect of drying on the extract from cucumber plants infected from different sources, it is

evident that the infective principle in the extract from mosaic cucumbers is incapable of withstanding drying. Six plants inoculated with the dried extract from mosaic cucumbers remained healthy, while two out of six other plants inoculated with the fresh extract became infected.

Resistance to heating. According to Doolittle (11), the expressed juices of mosaic cucumber plants lose their power of infection when heated above 70° C. The writer's experiments on the relation of temperature to the infective power of the virus of cucumber mosaic were almost entirely negative. In three experiments carried on in March, July, and August, 1924, to determine the effect of temperature on the infective principle in the extract from mosaic cucumber plants, the extract was exposed for 10 minutes to temperatures from 50° to 80° C. in 5° intervals. The treated extract was then inoculated into series of 4 to 6 plants, 74 plants in all being inoculated. All tests with the heated extract were negative except one, in which 1 out of 6 plants inoculated with the extract heated to 75° C. became mosaic, but a single infection is of little value as data. In one trial the check gave 1 mosaic plant, in another 2, and in a third none. It will be noted in the data given that a very small percentage of infection followed inoculation with the unheated juice; the controls and the negative data merely furnished an idea as to the rapidity of degeneration of the infective principle in cucumber mosaic.

Resistance to treatment with alcohol. In an endeavor to isolate a possible causal enzyme from juice extracted from mosaic cucumber plants, Doolittle treated the extracted juices with different percentages of alcohol. The time of treatment is not mentioned, but in no case was infection obtained when the alcohol precipitates were taken up with water and used to inoculate young cucumber plants. Of this work Doolittle says, "A few attempts were made to isolate a possible causal enzyme from the juices of mosaic cucumber plants. The fact that the juices of such plants usually lose their power of infection within 24 to 48 hours has proved an almost insurmountable obstacle in such work."

The writer, in a single series of experiments, obtained no infection following treatment of the extract from mosaic cucumber plants with different strengths of alcohol, but inasmuch as no infection appeared in the controls it is probable that the killing occurred because of the time taken for the treatment, and the results may again be interpreted only to show the short-lived nature of the virus.

The effect of dilution. Doolittle (11), in speaking of dilution experiments with cucumber virus, says, "These experiments show that dilutions of 1:1,000 are as potent as undiluted solutions, but while infections may result from those of 1:10,000 they have never taken place at higher dilutions."

Inoculations made with dilutions of the extract from mosaic cucumber plants gave no infection in the experiments of the writer. The control inoculations in all experiments were made following the other inoculations in order to eliminate the possibility of confusion in the results arising from the difference in time of extraction of the juices and the inoculations, for should infection result in the controls it could be surmised that the time of treatment for the remaining part of the experiment was not the factor responsible for any diminution in percentage of infected plants. In these experiments controls were made before and after the dilutions were made, but no infection was obtained in any of the plants. The absence of infection, even in the controls made a half hour after extraction, cannot be definitely explained, for there can be no doubt as to the plants from which the extract was taken being affected with mosaic.

Ability of the infective principle to pass filters. Doolittle found little loss in the infective nature of the extract from mosaic cucumber plants after passage through Berkfeld filters. He found, also, that all types of Chamberland filters are capable of retaining the infective entity of cucumber mosaic. In only 4 cases out of 60 inoculations was the filtrate from Berkfeld filters found infective to young cucumber plants. Since the infection occurred following inoculation with the filtrate from the finest grade of Berkfeld, W., it is safe to infer that the virus is filtrable through the coarser grades of Berkfeld, N. and V. A few inoculations with filtrates from Chamberland filters gave no infection. Since a low percentage of infections resulted in these experiments in the control inoculations made with extract kept for approximately the same length of time required for filtration, it is probable that the time factor was more important in destroying the infectiousness of the extracts than the filtration.

PROPERTIES OF THE INFECTIVE PRINCIPLE IN THE EXTRACTS FROM CROSS-INOCULATED PLANTS

The infective principles in the extracts from mosaic tobacco, tomato, and ground cherry plants have been shown in the preceding pages to react in an almost identical manner in their ability to successfully withstand certain vital tests. It is also shown that the infective entity in the extract from mosaic cucumber plants is incapable of withstanding the same tests in a comparable degree.

On account of the similarities of the reactions of the tomato and ground cherry extracts it was not thought possible to discern changes in the properties of the extract from one of these plants when inoculated with the extract of the other. For instance, in the case of the thermal death point, which was shown for both the extract from mosaic tomatoes and from mosaic ground cherries to be in the neighborhood of 85° C., it will be seen

that the possibility of a discernible change was less than in the same test on the extracts from mosaic ground cherries and from mosaic cucumbers, where there is a difference of 15° C. Consequently the chief comparisons were made with the extracts obtained from cross-inoculations between cucumber and ground cherry. The extracts of these two hosts appeared very unlike in resistance to tests on ageing and drying, and the cross-inoculations between cucumber and ground cherry more readily were made than those between cucumber and tomato, since the latter crosses required an intermediate host. After some preliminary work it was found that certain of the tests listed in the introduction did not offer such good opportunities for comparing viruses from different plants; consequently they were either slighted or dropped. The tests on ageing, drying, and heating offered the best possibilities of contrast, and, since the work was outlined with the idea of obtaining comparisons rather than determining the exact properties of individual viruses, these points have been emphasized.

PROPERTIES OF THE INFECTIVE PRINCIPLE IN THE EXTRACT FROM TOMATO PLANTS INOCULATED WITH THE EXTRACT FROM MOSAIC GROUND CHERRY PLANTS

Resistance to ageing. Experiments were made with the extract from tomato plants infected from mosaic ground cherry plants to determine the resistance of the virus therein to ageing. It was found that infection occurred following inoculation of young tomato plants with the virus 40 days after extraction. This period is not as long as those used in the tests on the infective principles taken as typical for tomato and ground cherry mosaic, but indicates that the viruses, or infective principles, in these two hosts behave in the same manner. In tests with extracts 1, 2, 8, 14, and 40 days old, in which 6 plants were inoculated with each extract, 6, 6, 3, 1, and 2 cases of infection resulted, respectively.

Resistance to drying. The results of a single series of inoculations show that the resistance to drying of the infective principle in the extract from mosaic tomatoes infected with the extract from mosaic ground cherry plants is similar to that of the infective principle in the extract from mosaic tomatoes infected with the extract from tomatoes. In this experiment 4 lots of 6 plants each were inoculated with extracts dried for 1, 2, 8, and 14 days; 6, 6, 3, and 2 infections resulted, respectively.

Resistance to heating. Effects of different temperatures on the extract from tomato plants inoculated with the extract from mosaic ground cherry plants are apparently identical with those on the extract from mosaic tomato plants or from mosaic ground cherry plants inoculated with the extract from plants of their own kind as the results in table 9 show. In all

eases the infective principle of the mosaic disease of such cross-inoculated plants is rendered inert between 85° and 95° C.

TABLE 9.—*The effect of temperature on the infective principle in the extract from mosaic tomato plants inoculated with the extract from mosaic ground cherry plants*

Date inoculated, 1924	Temperature in degrees C. (constant for 10 min.)	No. plants inoculated	No. plants diseased	Date observed, 1924
July 18	70	6	5	July 29
do	75	6	5	do
do	80	6	6	do
do	85	7	5	do
do	90	6	2	do
do	95	6	0	do
do	Unheated extract (Control)	6	6	do

Resistance to treatment with alcohol. The higher percentages of alcohol have no more effect on the infective principle in the extract from tomato plants infected with the extract from mosaic ground cherry plants than on the infective principle in the extract from tomatoes infected from other tomato plants, or that contained in the extract from ground cherry plants inoculated from mosaic ground cherries. In this experiment 4 lots of 6 plants each were inoculated with extracts treated for one hour with 70, 80, 90, and 95 per cent alcohol; 5, 5, 5, and 4 plants, respectively, became infected. All 12 controls inoculated with the untreated extract became infected.

The effect of dilution. The infective principle from tomato plants inoculated with the extract from mosaic ground cherry reacts to dilution in the same manner as that taken as typical for tomato, and as that taken from mosaic ground cherries. In a single experiment, inoculations with dilutions of 1:10, 1:100, 1:1,000, and 1:10,000 gave 5 out of 6, 5 out of 6, 3 out of 6, and 0 out of 6 infections, respectively. Twelve control plants inoculated with the undiluted extract became infected.

Ability of the infective principle to pass filters. Filtration experiments with the extract from tomato plants inoculated with extract from mosaic ground cherry plants, the results of which appear in table 10, show that the infective entity is capable of passing Berkfeld V and Chamberland F and B filters. The fact that infective filtrates were obtained from both Chamberland filters leads the writer to the assumption that the infective principle also passes the Berkfeld W filter, because this is coarser than the Chamber-

land B filter. Data on this point, however, could not be obtained at the time.

TABLE 10.—*Results of inoculating healthy tomato plants with the filtered extract from tomato plants inoculated with the extract from mosaic ground cherry plants*

Date inoculated, 1924	Filter used	No. plants inoculated	No. plants diseased	Date observed, 1924
July 17	Berkfeld W	6	0	July 29
do	do V	6	6	do
do	Chamberland B	6	3	do
do	do F	6	1	do
do	Unfiltered extract (Control)	12	12	do

PROPERTIES OF THE INFECTIVE PRINCIPLE IN THE EXTRACT FROM GROUND CHERRY PLANTS INOCULATED WITH THE EXTRACT FROM MOSAIC TOMATO PLANTS

Resistance to ageing. The extract from ground cherry plants infected with the extract from mosaic tomato plants shows a similarity to the typical virus of tomato and of ground cherry mosaic in its ability to retain its power of infecting young ground cherry plants a considerable time after extraction. After 84 days infection was obtained from inoculation with an unpreserved extract. Three lots of six plants each were inoculated with extracts 70, 75, and 84 days old, and 0, 3, and 2 infections resulted, respectively.

Resistance to drying. No experiments were made on the ability of the infective principle in the juice of mosaic ground cherry plants inoculated with the extract from mosaic tomato plants to withstand drying, on account of the fact that the similarity of the viruses of the two plants rendered a difference improbable, especially in view of the results from other tests on this extract; namely, age, resistance to alcohol, and relation to filters.

Resistance to heating. No thermal death point experiments were made with the extract from ground cherry plants inoculated with the extract from mosaic tomato plants since there is no difference in the virus of the two hosts and it was thought likely that there would not be sufficient change to make comparisons possible.

Resistance to treatment with alcohol. The infective entity in the juice of ground cherry plants inoculated with the extract from mosaic tomato plants is as resistant to high percentages of alcohol as the juice of ground cherry or tomato plants infected with the extract from mosaic plants of their own kind. In two series of six plants each, inoculated with the extract treated with 90 and 95 per cent alcohol for one hour, 2 plants in each

series became mosaic. Three of the 6 control plants inoculated with the untreated extract also became mosaic.

Effect of dilution. No dilution experiments were made with the juice of ground cherry plants inoculated with the extract from mosaic tomato plants, since it was not thought likely that there would be a sufficient difference in this respect from the extract from tomato and ground cherry plants inoculated with the extract from mosaic plants of their own kind to make a comparison possible.

Ability of the infective principle to pass filters. Filtration of the juice of mosaic ground cherry plants inoculated with the extract from mosaic tomato plants showed the infective particles capable of passing Berkfeld (grades W. N. and V) and Chamberland (grades F and B) filters. Table 11 shows the results of inoculations made with the filtrate from these different filters.

TABLE 11.—*Results of inoculating healthy ground cherry plants with the filtered extract from ground cherry plants inoculated with the extract from mosaic tomato plants*

Date inoculated, 1924	Filter used	No. plants inoculated	No. plants diseased	Date observed, 1924
May 22	Berkfeld W	4	4	June 1
do	do N	5	5	do
do	do V	6	5	do
do	Unfiltered extract (Control)	5	4	do
July 4	Berkfeld W	6	4	July 14
do	Chamberland B	6	5	do
do	do F	6	5	do
do	Unfiltered extract (Control)	6	5	do

PROPERTIES OF THE INFECTIVE PRINCIPLE IN THE EXTRACT FROM GROUND CHERRY PLANTS INOCULATED WITH THE EXTRACT FROM MOSAIC CUCUMBER PLANTS

The differences in the reactions of the extract from mosaic ground cherry and that from mosaic cucumber plants, and the ease with which the disease on one of these hosts might be transmitted to the other, offered better possibilities of comparison than in the case of any of the other cross-inoculations. The most striking results in experiments on the properties of the extracts from cross-inoculated plants are from the cucumber-ground cherry crosses, and the tests on ageing, drying, and heating. The other tests with alcohol, dilution, and filtration relationships have appeared so

nearly the same in all cases that nothing could be learned from comparisons of the results of tests on these points.

Resistance to ageing. Since the virus of cucumber mosaic becomes innocuous within a few hours after extraction, it would appear that the virus from ground cherry plants infected with the extract from mosaic cucumber plants would react in the same manner. This is not the case, however, for, as shown in table 12, the extract from ground cherry plants infected with the extract from mosaic cucumber proved infective after 29 days. From the work of Doolittle, a week exceeds the longest limit the virus of cucumber mosaic remains infective; in the present work 24 hours has been the longest period over which the juices of mosaic cucumber plants retained their power of infection. This fact indicates that the so-called virus of cucumber mosaic readily can acquire the property of the ground cherry virus of withstanding prolonged periods of ageing.

TABLE 12.—*The resistance to ageing of the infective principle in the extract from mosaic ground cherry plants inoculated with the extract from mosaic cucumber plants*

Date inoculated, 1924	Age of virus	No. plants inoculated	No. plants diseased	Date observed, 1924
Aug. 25	1 hour (Control)	6	2	Sept. 20
Aug. 5	24 hours	6	3	Aug. 23
Aug. 26	do	6	3	Sept. 20
Aug. 7	48 hours	6	2	Aug. 23
Aug. 26	do	6	4	Sept. 20
Aug. 30	5 days	6	3	Sept. 20
Aug. 12	7 do	6	3	Aug. 25
Sept. 3	9 do	6	1	Sept. 20
Aug. 25	20 do	6	1	Sept. 20
Sept. 3	29 do	6	2	Sept. 26

Resistance to drying. Although the infective principle in the extract from mosaic cucumber plants is absolutely incapable of withstanding drying in any degree, the extract from ground cherry plants inoculated with the extract from mosaic cucumber plants showed no such susceptibility to drying. After 29 days drying, this extract was still infectious. The results of these experiments, set forth in table 13, show that the infective principle of cucumber mosaic may be radically changed in its resistance to drying by transfer to the ground cherry.

TABLE 13.—*The effect of drying on the infective principle in the extract from ground cherry plants inoculated with the extract from mosaic cucumber plants*

Date inoculated, 1924	Length of drying period	No. plants inoculated	No. plants diseased	Date observed, 1924
Aug. 5	Fresh extract (Control)	6	2	Aug. 23
Aug. 6	24 hours	6	2	Aug. 23
Aug. 26	24 do	6	2	Sept. 20
Aug. 7	48 do	6	1	Aug. 23
Aug. 26	48 do	6	3	Sept. 20
Aug. 30	5 days	6	1	Sept. 20
Aug. 12	7 do	6	3	Aug. 25
Sept. 3	9 do	6	3	Sept. 26
Aug. 25	20 do	6	2	Sept. 20
Sept. 3	29 do	6	3	Sept. 20

Resistance to heating. Whereas the extract from mosaic cucumber plants is incapable of withstanding temperatures higher than 70° C., the same virus when transferred to ground cherry plants becomes capable of withstanding temperatures between 85° and 90° C. Three lots of 6 plants each were inoculated with extract treated for 10 minutes at 70°, 80°, and 90° C.; 2, 1, and 1 plants, respectively, became infected. Two of 6 control plants inoculated with untreated juice became diseased.

Resistance to treatment with alcohol. No experiments were made on the resistance of the infective principle in the sap of ground cherry plants infected with the extract from mosaic cucumber plants to treatment with different percentages of alcohol. The difficulty of discerning comparable differences in the reactions of the various viruses by means of this test has made experiments with it of doubtful value.

The effect of dilution. Dilutions of the sap of mosaic ground cherry plants inoculated with the extract from mosaic cucumber plants gave results practically identical with those obtained from dilutions of the viruses from other sources, and further show the difficulty of satisfactory comparisons of different viruses by this method. A dilution of 1:1,000 was found to be the highest dilution possible without reducing the infective powers of the extract. The results of the inoculations with dilutions of 1:10, 1:100, 1:1,000, and 1:10,000 in four lots of six plants each were 3, 1, 2, and 0 infections, respectively. Four of 6 control plants inoculated with the undiluted extract became mosaic.

PROPERTIES OF THE INFECTIVE PRINCIPLE IN THE EXTRACT FROM CUCUMBER PLANTS INOCULATED WITH THE EXTRACT FROM MOSAIC GROUND CHERRY PLANTS

A lack of time, together with the indications that the difficulty of working with a cucumber extract might be repeated in these experiments, led to the omission of several of the tests used with the other extracts. This seemed especially probable after it was found that the extracts from cross-inoculated cucumber plants showed no greater resistance to ageing and drying than those from cases of ordinary cucumber mosaic.

Resistance to ageing. The fact that the virus from mosaic ground cherry plants is capable of remaining infective for considerable periods of time after extraction does not render the extract from cucumber plants inoculated with the extract from mosaic ground cherry plants any more capable of withstanding ageing than the extract from cucumber plants infected with mosaic from any other source. This is shown in an experiment in which 3 lots of 6 young cucumber plants each were inoculated with extracts 1, 2, and 14 days old. No infections occurred following inoculation with either the 1- or 14-day-old extract, but one infection occurred following inoculation with the 2-day-old extract, a period well within the maximum age limit of cucumber virus as determined by Doolittle. A series of 10 control plants inoculated with extract 2 hours old showed only two cases of infection. This would indicate that even 2 hours' exposure attenuated the infectious nature of the virus.

Resistance to drying. Drying experiments with the extract from cucumber plants infected with the extract from mosaic ground cherry plants have shown that the ability of the ground cherry virus to remain infective after drying cannot be transmitted to the cucumber. In an experiment bearing on this point no infection occurred in any of the plants inoculated in lots of six with the extracts which had been dried for 1, 2, and 14 days. Two out of ten controls inoculated with the fresh extract became mosaic.

PROPERTIES OF THE INFECTIVE PRINCIPLE IN THE EXTRACT FROM MOSAIC CUCUMBER PLANTS INOCULATED WITH THE EXTRACT FROM MOSAIC TOMATO PLANTS BY MEANS OF GROUND CHERRY PLANTS AS INTERMEDIATE HOSTS

It is possible that the results of these experiments can be interpreted merely as additional experiments with the juice of mosaic cucumber plants infected with the extract from mosaic ground cherry plants, but, should the original hypothesis of a specificity of the virus be adhered to, we have in these experiments been dealing with cucumber plants infected with tomato mosaic, even though the tomato virus first passed through the ground cherry.

The explanation given under the preceding section may be repeated here with the addition of a statement of the difficulty in making inoculations on a scale large enough for juice extraction, after passing the virus through an intermediate host plant. This was a time consuming task, and, since the extracts showed the same reactions to ageing and drying as those of typical mosaic of cucumber, the work was limited to these two tests.

Resistance to ageing. Although the viruses of both tomato and ground cherry mosaic are long-lived, the extract from cucumber plants inoculated with the extract from mosaic tomato plants by using ground cherry plants as intermediate hosts did not show a similar property. In four tests, in each of which 6 plants were inoculated with extract 1, 2, 6, and 14 days old, no infection was secured, although the 8 check plants inoculated with 1-hour-old extract gave 3 mosaic plants.

Resistance to drying. It was found that the infective entity in the juice of mosaic cucumber plants inoculated with tomato mosaic by using ground cherry plants as intermediate hosts was no more resistant to drying than the juice of cucumber plants either naturally infected or inoculated with the extract from mosaic cucumber plants. This is shown by the fact that in four tests, in each of which 6 plants (in one case 7) were inoculated with extract after 1, 2, 6, and 14 days' drying no infection was secured, although 3 of the 8 control plants inoculated with 1-hour-old extract became mosaic.

GENERAL DISCUSSION

The results of the present work have shown that the infective agencies in the juices of mosaic tomato and ground cherry plants behave in practically the same manner and are also apparently identical in character with the virus of tobacco mosaic in respect to ageing, drying, heat, dilution, treatment with alcohol, and filtration. The expressed juices of all these hosts are extremely resistant to such treatments and are in marked contrast to the extracts from mosaic cucumber plants in which the virus rapidly loses its infective power after extraction. A summary of the results of tests on the various viruses is given in table 14.

It is also known, however, that tomato mosaic may be transmitted to cucumber by means of the ground cherry as an intermediate host and that cucumber mosaic may be transmitted to tomato in the same manner. Since the symptoms produced by such inoculations seemed the same as those associated with what are considered the typical mosaics of the respective hosts, it seemed possible that the causal agencies of tomato and cucumber mosaic might be the same.

Such an interpretation of the results of these cross-inoculations, however, is open to the objection that the expressed juices of tomatoes and cucumbers show radically different properties, and on this basis it might

TABLE 14.—*Summary of experiments showing the effects of various treatments on the infectivity of mosaic viruses from different sources*

Virus or extract	Infectious after					
	Ageing	Drying	Heating	Diluting	Treatment with alcohol	Filtration
Tobacco	3 yrs.	2 yrs.	85°–90° C.	1:1,000	½ hr. in 80 per cent	Passes Berkfeld and Chamberland
Tomato	138 days	30 days	85°–90° C.	1:1,000	1 hr. in 95 per cent	Passes Berkfeld
Ground cherry	69 days	23 days	85°–90° C.	1:1,000	1 hr. in 95 per cent	Passes Berkfeld
Cucumber	24–48 hrs.	Less than 24 hrs.	70° C.	1:1,000	Negative	Passes Berkfeld
Tomato inoculated from ground cherry	40 days	14 days	85°–90° C.	1:1,000	1 hr. in 95 per cent	Passes Berkfeld and Chamberland
Ground cherry inoculated from tomato	84 days	No test	No test	No test	1 hr. in 95 per cent	Passes Berkfeld and Chamberland
Ground cherry inoculated from cucumber	29 days	29 days	85°–90° C.	1:1,000	No test	No test
Cucumber inoculated from ground cherry	2 days	Negative	No test	No test	No test	No test
Cucumber from tomato through ground cherry	Negative	Negative	No test	No test	No test	No test

seem probable that we are dealing with two distinct causal entities possessing the same host range. The results of the present investigations, however, have shown that the reactions of the infective principle in the juices of mosaic cucumber, tomatoes, or ground cherries always have been the same for a given species, regardless of the source of infection. The extracts from ground cherries infected with the extract from mosaic tomatoes exhibit the same reactions as those from ground cherries inoculated with the extract from mosaic cucumbers, and the same results have held true in the case of cucumber and tomato when inoculated with the extract from either of the other two hosts studied. In short, the so-called properties of the mosaic virus seem to be determined by the character of the juices of the host plant in which the disease occurs.

This variable nature of the infective principle makes it evident that the use of the term "virus" to connote the expressed juices from mosaic plants is misleading, and makes it more necessary that the actual infective entity be isolated from these expressed juices before determining the actual properties and characters of the virus, or infective principle, since by our present methods the tests used indicate changes in the medium rather than in the virus. The results of these studies, however, together with the results of the cross-inoculation experiments of the writer and others seem to indicate a single causal agency in the case of the mosaic diseases of the cucumber, ground cherry, and tomato in so far as their response to a series of arbitrary tests is concerned.

An interesting point in connection with experiments in which the extracts were heated to different temperatures was the relationship between the thermal death point of the viruses and the point at which coagulation occurred. In the case of tomato and ground cherry extracts, the thermal death point was in the neighborhood of 85° C., and it was near this point that complete coagulation took place. In the ground cherry extract two distinct points of coagulation were noticed. The first coagulation separated the green chlorophyllous material from the extract, leaving a grayish substance behind, and occurred in the neighborhood of 65° C. The next coagulation precipitated the grayish substance in curdy masses, separating it from a clear amber liquid. The temperature at which this coagulation occurred coincided with the thermal death point of the virus. This relationship was also noticed in the case of the cucumber, the point of coagulation and the thermal death point both of which are practically the same, 70° C. In experiments in which alcohol was added to the extract from mosaic plants, coagulation also occurred, but there was apparently no correlation between the point in the addition of alcohol at which coagulation occurred and the one at which the virus was rendered innocuous, which in the case of alcohol treatment was not definitely determined. By a combination of these two methods of coagulation, heating and addition of alcohol, under delicately controlled conditions and with suitable filtration methods, a separation of the mosaic extracts into several parts seems possible; one of these parts will be closer to the actual virus than anything heretofore obtained.

SUMMARY

1. This paper presents the results of experiments to determine the properties of the infective principle, or virus, from typical cases of mosaic on the cucumber, tomato, and cultivated ground cherry; and to determine the changes that occur in any one of these viruses when transferred by cross-inoculations to either of the other two hosts.

2. These experiments included studies on the reactions of the various infective principles to ageing, drying, heat, alcohol, dilution, and filtration. A summary of the reactions of the various extracts to these tests is given in table 14.

3. The behavior of the expressed juices of mosaic tomato plants appears to be the same as that described by other workers in the case of tobacco mosaic. The tomato mosaic virus withstands ageing, and can be diluted to 1:10,000 and still produce infection. Treatment for one hour with alcohols ranging in strength from 33 to 95 per cent did not destroy its power of infection. The thermal death point in the case of tomato mosaic appears to lie between 85° and 90° C. The infective principle is also capable of passing all grades of Berkfeld filters.

4. Juices extracted from mosaic ground cherry plants reacted in the same manner as the juices from mosaic tomato plants in tests on ageing, drying, heating, dilution, and treatment with alcohol. Filtrates from Berkfeld filters were also infective.

5. The infective principle in the expressed juices from mosaic cucumber plants is incapable of withstanding ageing, drying, heating, and treatment with alcohol in any degree comparable to that of the virus of the mosaic diseases of tomato and ground cherry. The cucumber virus reacts in the same manner to dilution and filtration through Berkfeld filters as the viruses from the other three plants named.

6. The reactions of the virus in the juice expressed from tomato plants inoculated with the extract from mosaic ground cherry plants were the same as those from tomato plants inoculated with the extract from mosaic tomato plants.

7. The reactions of the infective principle from ground cherry plants inoculated with the extract from mosaic tomato plants were the same as those of the virus from ground cherry plants inoculated with the extract from mosaic plants of their own kind.

8. The juice from ground cherry plants inoculated with the extract from mosaic cucumber plants showed the same reactions as the juice from ground cherry plants inoculated with the extract from mosaic ground cherries.

9. The properties of the extract of cucumber plants inoculated with the extract from mosaic ground cherries were the same as those of other mosaic cucumber plants either naturally infected or inoculated with extract from other cucumber plants.

10. The juices extracted from mosaic cucumber plants infected with the extract from mosaic tomato plants by means of ground cherry as an intermediate host showed no differences from the typical cucumber virus.

11. These experiments have shown that the properties of the mosaic virus of a given plant may be decidedly changed by transferring it to another host. The properties of the viruses from mosaic plants of a certain species also appear to be the same, no matter what the source of infection. This fact indicates that there may be a single causal agent for all the mosaic diseases studied here.

12. Experiments in which the extracts from mosaic plants were treated at different temperatures showed that the thermal death point of the infective principle in the extract and the temperature at which coagulation of the extract occurs are practically the same.

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RESISTANCE OF PEAS TO ROOTROT[1]

FRED REUEL JONES

INTRODUCTION

In the study of diseases of the root system of the pea plant, with which the writer has been concerned for several years, no phase of the general study has proven more elusive of precise statement than that of resistance in certain varieties. The fact that certain varieties were more or less resistant had been observed on the trial grounds maintained by seed companies before it became a matter of investigation and was reported in phytopathological literature. In the several demonstrations of resistance which have been observed by the writer, more than one fungous parasite of the pea plant has been found; but in all cases previous to 1925 the parasite which seemed to be most abundantly present and most aggressive in its attack upon the plant was *Aphanomyces euteiches* Drechsler, described in a previous paper as the cause of pea rootrot. In consequence of this condition, it has been assumed that resistance shown by the plant as a whole was resistance to the destructive action of this parasite or perhaps to some of the consequences of its invasion. In a previous paper[2] summarizing work done up to the spring of 1924, several ways are suggested whereby the resistant varieties may escape injury. Among the more important appeared to be delayed infection, slower progress of the parasite through the root cortex; formation of a secondary periderm, and especially resistance of the vascular cylinder of the root to invasion by soil fungi after the primary cortex has been destroyed. The present paper records the progress which has been made in the study of resistance of peas in 1924 and 1925.

FIELD TRIALS IN 1924

The varieties chosen for closest study in 1924 are given in table 1.

[1] This study of resistance in peas to disease is a portion of an investigation of diseases of peas conducted by the Office of Cotton, Truck and Forage Crop Disease Investigations of the Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C., in cooperation with the Wisconsin Agricultural Experiment Station.

[2] Jones, Fred Reuel, and Charles Drechsler. Root rot of peas in the United States caused by *Aphanomyces euteiches* (n. sp.). Jour. Agr. Res. 30: 293–325. 1925.

TABLE 1.—*Varieties of peas studied in 1924*

Relative earliness	Varieties	
	Resistant	Susceptible
Early	Rice No. 330	Alaska
Medium	Horal	Horsford
Late	Black Eyed Marrowfat	White Marrowfat

Planting was made at three locations on infested soil where peas had failed the previous year. At Madison, Wisconsin, planting was made by the writer; at McMillan, Michigan, by Dr. Wilber Brotherton, Jr.; and at Columbus, Wisconsin, the first four varieties were planted by the Columbus Canning Company[3] on a commercial scale for demonstration. Unfortunately, the Madison planting was greatly damaged by a heavy shower and was of little value. The soil at Columbus was so hard during an early period of dry weather that roots could not be removed and examined as extensively as was desired. Soil conditions at McMillan, Michigan, were favorable for the removal of roots at all times. In all of these plantings rootrot caused by *Aphanomyces* was the first disease of general occurrence observed, and it developed abundantly and apparently uniformly.

In view of the outcome of this work, it seems unnecessary to report in detail the results of these comparisons. Suffice it to say that, in the early growth of the plants, considerable differences in rate of root growth was found in each location between the varieties, but the differences were not maintained consistently in the three locations.

Apparent delayed infection and retarded progress of the parasite. Two of the varieties, Horal and Black Eyed Marrowfat, seemed to resist infection by *Aphanomyces* in two of the trials. At Madison, a portion of a row of Black Eyed Marrowfats on June 25 yielded 27 plants, seven of which were free from visible infection, while a corresponding row of White Marrowfats yielded only 19 plants, every one of which was thoroughly stripped of root cortex. The roots of the 20 infected plants were not nearly so extensively invaded as were those of the susceptible variety. A similar examination of plants at McMillan planted May 2 and washed from the soil July 11 gave results shown in table 2.

From table 2 it is clearly seen that, although the number of plants examined is small, Horal shows hardly half as large a percentage of infection

[3] The field studies of resistance recorded here have been made possible by Dr. Wilber Brotherton, Jr., who has maintained plots for the writer at McMillan, Michigan, and by The Columbus Canning Company, Columbus, Wisconsin, which has maintained comparative trials of varieties in infested fields for two years.

as the susceptible varieties, and Black Eyed Marrowfat hardly more than a third. These differences in percentage are inadequate to express the entire difference so far as apparent injury was concerned. The diseased plants of a resistant variety were in no case as extensively invaded as were those of the susceptible varieties, a difference that is not readily determined by measurement. When the next examination of the root systems was made on July 31, there were few root systems of any varieties left uninvaded by *Aphanomyces*. The resistant varieties, except No. 330, showed the greater number of infections, but the count of uninvaded plants at this time expresses even less completely the difference in the general condition of the root systems. Between Alaska and No. 330 there was little difference in apparent root injury. The only Horsford plants showing many living roots were a few whose taproots had been destroyed early and which had developed a new root system in the surface soil from the base of the epicotyl. Even the most damaged root systems of Horal plants showed a considerable number of living tertiary rootlets growing from secondary roots deprived of cortex. The same contrast appeared between Black Eyed and White Marrowfats.

TABLE 2.—*Percentage of plants of six varieties of peas invaded by Aphanomyces. Planted at McMillan, Michigan, May 2, 1924. Examined July 11*

Variety	No. plants with rotted root systems	No. plants free from rootrot	Percentage diseased plants
Alaska	39	9	81.0
No. 330	21	3	87.0
Horsford	29	11	72.5
Horal	24	29	45.0
White Marrowfat	57	1	97.7
Black Eyed Marrowfat	18	45	28.5

In contrast with the preceding observations, it must be recorded that at Columbus, Wisconsin, the roots of the Horal pea were invaded just as rapidly by *Aphanomyces* as were those of the susceptible Horsford, but that they did not die as rapidly after being stripped of primary cortex, and that resistance was just as striking here as in the other trials.

Secondary periderm. Comparison of rate and extent of development of the secondary periderm that might protect roots deprived of cortex was made chiefly at McMillan. No difference was observed in behavior between Alaska and No. 330. Periderm development was very slight and incomplete in the taproots of both varieties. Horal showed a greater develop-

ment of periderm than Horsford, and Black Eyed Marrowfat than White Marrowfat; but periderm development was so tardy and incomplete that it seemed unlikely that it contributed greatly toward resistance.

Secondary invasion. In all of the comparisons of susceptible and resistant varieties which have been made in the three locations, one difference has always been found between them. The vascular cylinder of resistant varieties remains free from secondary fungous invasion long after the cortex has been destroyed. For example, in a comparison of Horsford with Horal showing apparently equal injury judged from external appearance of the root systems, razor sections show that, while in Horal only the primary cortex is invaded, in Horsford fungous mycelium is found in some of the larger vessels, and often much of the secondary phloem is disorganized and decayed. All this occurs before the plants above ground have registered any indication of disease. In all varieties, the epicotyl and upper portion of the taproot appear to be the regions where secondary invasion progresses most rapidly and does greatest damage. In resistant varieties, vascular elements, when penetrated by fungous mycelium, usually become filled with a yellow gummy substance which seems to check the invasion, while such yellow discoloration does not appear in the susceptible varieties, where fungous mycelium appears to pass readily from cell to cell. From these examinations it appears that all of the resistance in No. 330 and much of the resistance in the other varieties examined is likely to be found in resistance of the vascular cylinder of the root to invasion and destruction by fungi which enter after the cortex has been destroyed by *Aphanomyces*.

GREENHOUSE STUDY OF DELAYED INFECTION AND RETARDED PROGRESS OF THE PARASITE

In the winter of 1924, efforts were made to demonstrate in the greenhouse ability of resistant varieties to delay infection or the progress of *Aphanomyces* through the roots. In the first trial, peas were planted in boxes 8 inches deep with screen wire bottoms. These boxes were set on moist sand. When the taproots of the young plants had entered the sand, the boxes were lifted and the sand flooded with a suspension of zoospores of *Aphanomyces*. After a time the plants were washed from the soil, and the distance to which the taproots showed softening from decay was measured. The measurements obtained in one trial are given in table 3. In this trial the fungus has progressed a little further through the susceptible variety than through its corresponding resistant variety, but the difference is not large.

In another series of experiments two wire-bottomed boxes of soil 4 inches deep, separated by a space of two inches, were made to fit closely in the

rectangular metal cans used in Wisconsin soil temperature tanks. Peas were planted in the upper box, and the taproots passed through the space separating the two boxes into the lower box of soil. Inoculation was made by pouring suspensions of zoospores on the surface of the soil in the lower box. By this device the time of infection could be easily observed by the discoloration and softening of root cortex at the surface of the soil.

TABLE 3.—*Comparison of rate of progress of the fungus Aphanomyces euteiches through the cortex of roots of peas under identical conditions in each of two trials*

Variety	First trial 9 days at about 20° C.		Second trial 12 days at 20–21° C.	
	No. plants measured	Average distance of invasion (cm.)	No. plants measured	Average distance of invasion (cm.)
Alaska	37	7.0	12	10.00
Rice's No. 330	16	6.0	10	7.90
Horsford	31	7.2	5	10.60
Horal	23	6.6	6	11.20
Black Eyed Marrowfat	13	6.7	10	10.60
White Marrowfat	23	8.1	8	11.30
Yellow Admiral			10	9.55
Green Admiral			7	8.00

Some difficulty was encountered in the use of this device, since the roots passing through the space between the two soil layers were sometimes readily killed by molds which gained entrance, even though the entire apparatus was sterilized before the peas were planted. The root ends were also readily damaged by drying if the upper soil became at all dry. However, in several trials roots in healthy condition were inoculated at the soil surface of the lower box and were observed as the fungus advanced up the taproot into the soil above. In no case was infection of resistant plants delayed beyond that in susceptible plants. There was no conspicuous difference in rate of progress. A typical set of measurements is given in table 3. Here again, with the exception of one pair, there is a difference in favor of the resistant plant, but a difference so slight that it cannot be regarded as significant. Resistance as it occurs in the field cannot be ascribed to such slight retardation of growth of the fungus in the host as is shown here.

FIELD TRIALS IN 1925 AND RESISTANCE TO WILT

Field study of resistance was continued in the spring of 1925. Unfortunately the trial plats at McMillan, Michigan, were discontinued. The

Columbus Canning Company at Columbus, Wisconsin, continued demonstration plats, using a larger number of resistant and susceptible varieties. They were planted on a rootrot infested field on which peas had not been grown for several years. Although there was little rain in early spring, peas germinated and grew fairly well, but rootrot did not appear until late in the season, and then only in small areas. Nevertheless, even though rootrot was absent, susceptible varieties like Horsford and Advancer at Columbus died off almost as completely as in years when rootrot was present, although a little later in the season. Owing to great injury from frost, it was not possible to compare Alaska and No. 330 in a satisfactory manner, but it appeared that Alaska suffered relatively little when compared with previous trials. In addition to the resistant varieties already considered, the Green Admiral pea showed high resistance, if not immunity.

The dying plants of susceptible varieties showed the characteristic symptoms of the wilt disease found by Linford[4] the previous summer, and from these plants the characteristic fungus associated with wilt was repeatedly isolated. It appears, then, that resistance shown by peas at Columbus in 1925 was resistance to wilt. Furthermore, it is probable that wilt has been present at Columbus and perhaps in other experimental plats in previous years, but was obscured by the earlier development of rootrot under usual conditions of rainfall, and that, in consequence, resistance to wilt was one of several factors in the resistance to parasitic invasion, all of which was ascribed to *Aphanomyces*. The frequency and importance of this factor in resistance in past experiments cannot be estimated. It does not seem likely to the writer that this factor has been present in all of the demonstrations of resistance that have been studied. Unless peas can, upon occasion in the field, develop greater resistance to *Aphanomyces* than was demonstrated in the greenhouse trials here described, it appears that resistance to *Aphanomyces* alone is but a small factor in this total of resistance; but it is still possible that the vascular cylinder of some varieties is resistant to destruction by soil fungi after the cortex has been destroyed, a form of resistance that may be coincident with resistance to wilt, or that in certain instances unrecognized root destroying fungi to which some varieties are resistant have occurred in conjunction with *Aphanomyces* in field trials. At present it appears that investigation in these several directions promises to lead to a comprehensive definition of the nature of resistance of peas to soil infesting fungi.

[4] Jones, Fred Reuel, and M. B. Linford. Pea disease survey in Wisconsin. Wis. Agr. Exp. Sta. Res. Bul. 64. 1–31. 1925.

SUMMARY

1. Resistance to injury from rootrot has been shown consistently by several varieties of peas observed in trial plats at McMillan, Michigan, and Madison, Wisconsin, during several years. Three varieties showing high resistance and three varieties showing conspicuous susceptibility were selected for comparative study in field and greenhouse to determine the difference in behavior of these varieties toward *Aphanomyces euteiches,* which appeared to be the most important cause of disease.

2. In field trials in 1924 one of the resistant varieties showed no delayed infection by *Aphanomyces* nor slower progress of this parasite in destruction of cortex of roots, while two varieties showed conspicuous resistance of this character in the trial at McMillan, but less or none of such resistance in the trials at Madison and Columbus, Wisconsin, where apparent resistance, judged by growth of the plants, was as great.

3. Resistant varieties in all locations remained comparatively free from fungous invasion in the vascular cylinder of root and epicotyl after the cortex was destroyed by *Aphanomyces,* while susceptible varieties were quickly invaded.

4. Greenhouse trials have failed to demonstrate an important degree of resistance to *Aphanomyces* in roots of resistant varieties.

5. In a field trial at Columbus, Wisconsin, in 1925, rootrot was largely prevented by drought. Susceptible varieties were damaged or destroyed by a wilt disease, while resistant varieties remained free from apparent injury.

6. From this experience it appears that resistance, as it is observed in the field, is the sum of several factors. Resistance to rootrot caused by *Aphanomyces* appears to be a very small factor. Resistance to wilt is in some localities a large factor. Other apparent factors whose importance has not been determined are resistance to secondary invasion of roots injured by *Aphanomyces,* and resistance to other root destroying fungi of less conspicuous importance in the soil.

MADISON, WISCONSIN

THE IMPORTANCE OF CONTROLLING CELERY BLIGHT IN THE SEEDBED

A. G. Newhall

Observations and experiments during the past four years in the celery fields of western New York have brought out quite strikingly (a) the importance of the seedbed as the source of inoculum both for late blight caused by *Septoria apii* and bacterial blight or leaf spot caused by *Pseudomonas apii*, and (b) the benefit resulting from protecting the seedlings with a copper fungicide.

Many authors have pointed out that certain seed-borne and soil-harbored pathogenes attack their hosts before they are out of the seedling stage. Several investigators have recommended more recently that celery spraying be commenced in the seedbed (3, 5, 6). There is some evidence that good control of tobacco wildfire may be obtained by this practice (1, 2). Data are presented here which indicate that delaying primary infections for 5 or 6 weeks in the case of celery blights by dusting the seedlings may be reflected later in the season by substantial reduction in blight development and at harvest by a corresponding increase in yield.

It has been recognized for some time that the late blight fungus may live over in the soil or on the seed and is often carried with the seed. The method of overwintering of the bacterial blight pathogene, on the other hand, is not so well understood. It is not likely that seed transmission is the common method, for this disease is rare, if present at all, in the celery seed growing districts. Moreover, in the muckland regions of New York State, where the disease is common, it is much more prevalent in fields where celery follows celery repeatedly than where a two-year rotation is practiced. The important fact at present is that, in certain seasons characterized by frequent or prolonged rains in June, the blight pathogenes become established on celery plants while they are still very small and before they are removed from the seedbed. Primary lesions both of late blight and bacterial blight have been found repeatedly under these conditions on plants only 5 or 6 weeks old.

The value of growing the plants in a clean seedbed was indicated by the following observations. On one farm plants for the field were selected from

TABLE 1.—*Field counts of blight[a] on plants from dusted and untreated seedbeds, 1923 and 1924*

Seedbed location, history and treatment	No. of plants examined	Percentage developing blight	Average no. of spots per plant	No. of dead or yellow leaves per plant	Yield in crates per acre	Percentage increase in yield
a. Old celery muck; seedlings dusted twice	1,000	3.9				
b. Same not dusted	1,000	15.4				
a. Old celery muck; moist situation, dusted 3 times	1,000	1.2			370	16
b. Same not dusted	1,100	26.3			321	
a. Old celery muck; moist, dusted 3 times	2,355	5.9	355			
b. Same not dusted	1,994	27.+	1,154			
a. Old celery muck; moist, dusted 3 times	500	14.2	163			
b. Same not dusted	500	93.0	1,989			
a. Old celery muck; dusted twice	500	29.0	112	1.2	383	36
b. Same not dusted	500	87.0	979	2.8	280	
a. New muck never cropped to celery; no treatment	1,000	6.4	145	.8	420	6.4
b. Old muck; no treatment	1,000	50.6	1,087	3.0	395	

[a] Both late blight, caused by *Septoria apii*, and bacterial blight, caused by *Pseudomonas apii*, present. All others bacterial blight only.

two seedbeds, one located on old muck which had grown blighted crops of celery in previous years, and the other on new muck. Neither seedbed received any fungicidal treatment. Plants from the two seedbeds were transplanted to the same field in July but were set in separate blocks of approximately an acre each. Six weeks later examination of 2,000 plants in this field showed that 50.6 per cent of the plants from the old muck seedbed were spotted, while only 6.4 per cent from the new muck were diseased (table 1). In other words, there were over seven times as many blighted plants from the old muck seedbed.

Apparently few workers have appreciated the number of plants which become infected in the seedbed and which are not detected at transplanting time. To illustrate this point, a seedbed was selected where blight was known to have existed the year before and where a very slight amount of infection was found in two small areas. Any celery grower would have pronounced it a clean seedbed. The day after this examination the plants were set out in the field. Three days later a very careful examination was made of all the plants in 33 rows 65 feet in length, and a stake was placed beside each spotted plant. Out of 7,690 plants examined, 83 were found to be affected by bacterial blight. The area amounted to one-fifth of an acre, which meant that 415 focal points for blight development per acre had come out of this seemingly healthy lot of seedlings. The distribution of these plants is shown in figure 1, a photograph of about one-third of the area examined.

Experiments were initiated in 1923 by the author (4) to determine the value of dusting to protect the seedlings from the time they were half an inch high until they were transplanted to the field. This procedure had already been tried by at least one enterprising celery grower, who had observed less blight all through the season on plants taken from seedbeds which he had sprayed than on plants from untreated seedbeds. On four farms 20–80 copper-lime dust was applied to portions of the seedbeds. A Niagara blower gun or hand duster was used, and from two to four applications were made at approximately seven-day intervals, beginning when the plants had developed their first true leaves. On two of these farms blighted celery had occupied the land the preceding year. Furthermore the moisture supply was exceptionally close to the surface, thus presumably favoring the blight pathogenes. On the other two farms, however, celery had not been grown for several years. Bacterial blight was found in the untreated portions of the beds in abundance on the first two farms, and on one of them Septoria blight was also abundant. But no blight was found on the other farms before the plants were set out in the field. The dusted plants were

set in a three-row block alternating with blocks of undusted plants. All received the same treatment after they were transplanted to the field.

During the last of July, after the plants had become well established, the fields were inspected and a record made of the number of plants showing blight spots (table 1). In one field, out of 1,000 plants which had been dusted twice in the seedbed, 39 plants, or 4 per cent, were spotted. In the same field, out of 1,000 plants from the undusted portion of the seedbed, 154, or 15 per cent, were found spotted. In another field, out of 1,000 plants which had been dusted three times in the seedbed, only 13, or 1.3 per cent, were diseased, while of an equal number from the undusted portion of the seedbed 290, or 29 per cent, showed blight spots. So there were in July from 4 to 22 times as many focal points from which the blight pathogenes could spread in those parts of the fields set with plants which had not been protected in the seedbed. In the last case above, the difference in blight was evident throughout the season even to the casual observer. Both late

FIG. 1. Stakes show where blighted seedlings had been set; 415 focal points for blight development per acre. Plants were taken from seedbed in continuous celery culture. These had not been sprayed or dusted but looked healthy to the casual observer at transplanting time.

blight and bacterial blight were abundant throughout this field. At harvest time three rows of plants which had been dusted in the seedbed were found to fill 18 crates, weighing a total of 1,950 pounds; while three adjacent check rows filled but 16 crates, weighing 1,750 pounds. This increase of 16 per cent amounted to 49 crates per acre.

In 1924 the experiments were repeated on five other farms. From two to three applications of 20–80 copper lime dust were made to portions of the

seedbeds. As in the previous season, on two of the farms there appeared to be no benefit from dusting the seedlings in the bed. Practically no blight developed on either the dusted or untreated plants until midsummer, when the growers commenced spraying or dusting the fields themselves. This is thought to be due to rotation of the seedbeds and to their well drained locations. On the other three farms, however, as table 1 shows, there were 3, 4½ and 6½ times as many blighted plants by midseason in those portions of the fields set with plants which had not been dusted in the seedbed. If the actual number of spots of blight per plant are considered, there were 3, 8½ and 12 times as many spots where the plants had not been dusted in the seedbed.

In 1924 also, increases in yield similar to those mentioned for 1923 were obtained. For example, on that part of one farm planted from a seedbed which had received two applications of 20–80 copper lime dust and which was relatively free from disease, there was an increase in yield of 103 crates per acre. On another farm where part of the plants came from a seedbed located on new muck and which remained relatively free from blight throughout the season, there was an increase in yield of 25 crates to the acre over that portion of the field set with plants from the old muck seedbed.

It is evident, therefore, that, if the grower can not choose new muck for his celery seedbed, and it is often undesirable to do this on account of soil moisture conditions, it is then highly desirable to protect the young seedlings in the seedbed. From the time the plants put out their first pair of true leaves until they are transplanted, 2 to 4 applications of a copper fungicide should be made at suitable intervals. The frequency of the applications will depend on rainfall and the rate of development of the plants, the aim being to keep them well covered at all times. No injury has been noted even from large quantities of copper-lime dust. It is believed that the fungicide acts not only as a protective coating on the plants but also inhibits or even kills the pathogenes which may be residing close to the surface of the soil. In all events the early applications made before the plants were large enough to completely shade the ground were the more important ones. Bordeaux mixture is known from earlier work (4) to be equally as effective as copper-lime dust in controlling these two blights of celery. However, on account of the convenience of the dusting method, growers who would never have bothered with a hand sprayer are now using a hand duster without complaint and with excellent results. The long quiet evenings in June are ideal for treatment with a minimum expenditure of time and material. The dust settles close to the ground in a dense layer, giving a very complete covering.

A few applications to the seedbed at a very small cost have been found to save one or more applications of fungicide, or of fertilizer, to the entire field later in the season. It is a most reasonable form of insurance against both late and bacterial blights. In fact it is at present probably our only safe means of protection against the seed-borne late blight organism. Seed treatment may cause more or less injury, depending on the age and vitality of the seed; and furthermore the late blight pathogene may live over in the soil, in which case seed treatment would be useless.

SUMMARY

1. Both late blight (caused by *Septoria apii*) and bacterial blight or leaf spot (due to *Pseudomonas apii*) of celery have been found in considerable abundance on small plants in out-of-door seedbeds.

2. When two to four applications of 20–80 copper lime dust were applied while the plants were in the seedling stage, a marked reduction in subsequent blight development throughout the season was obtained in six out of ten fields. The control of blights was reflected in substantial increases in yields at the end of the season.

DEPARTMENT OF PLANT PATHOLOGY,
CORNELL UNIVERSITY,
ITHACA, N. Y.

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SMUT OF WESTERN RYE GRASS

W. P. Fraser and G. A. Scott

A smut of western rye grass was first brought to the attention of the senior author in 1916 on specimens collected at Saskatoon and transmitted by Professor James Murray of MacDonald College. He reported about 60 per cent infection. More recently this smut has been collected at Winnipeg, Brandon, Indian Head, Scott, Lacombe, and at a number of other places. There was usually about 10 to 15 per cent infection where the collections were made. One district in northern Saskatchewan, Sturgeon River, reported as high as 90 per cent of smut in a field of western rye grass. As this grass is largely used for hay in the prairie provinces of Canada, and as the smut reduces its value for feeding purposes and seriously interferes with the production of seed, a study of the smut seemed desirable.[1]

The smut attacks the spikelets, destroying the ovaries and usually the bases of the glumes (Fig. 1), although frequently the outer glumes are not affected. The sori are large, irregular, rather firm at first, but finally dusty. The spore mass is dark brown to black in color. Usually all the spikelets of the head are affected, but sometimes only the upper ones are smutted. The spores are usually spherical, sometimes oval, dark brown, finely verrucose, and mostly 8–11μ in diameter, averaging 9.2μ. The spores germi-

TABLE 1.—*The effect of treating seed of western rye grass for control of smut*

Year	Place	No. of rows of each treatment	Per cent smut in rows from seed treated in different ways		
			Seed untreated	Seed dusted with smut spores (Check)	Seed dusted with smut spores and treated with formaldehyde solution (1–320)
1919	Indian Head	2	0	15.0	0
do	Saskatoon	2	trace	8.0	0
1920	Indian Head	2	0	12.5	0
do	Saskatoon	2	0	23.3	0
1921	Indian Head	1	trace	80.0	0
do	Saskatoon	1	trace	75.7	0
1922	Saskatoon	1	trace	24.6	0

[1] Fraser, W. P. A smut of western rye grass. Phytopath. **10**: 316. 1920.

nated readily in 5 per cent sugar solution and less freely in water. Sporidia are produced in sugar solution in a few hours (Fig. 2).

Experiments carried out during the seasons 1919–1922 indicated that the smut was carried over from season to season by spores clinging to the seed, and that seed treatment with formaldehyde solution would prevent the

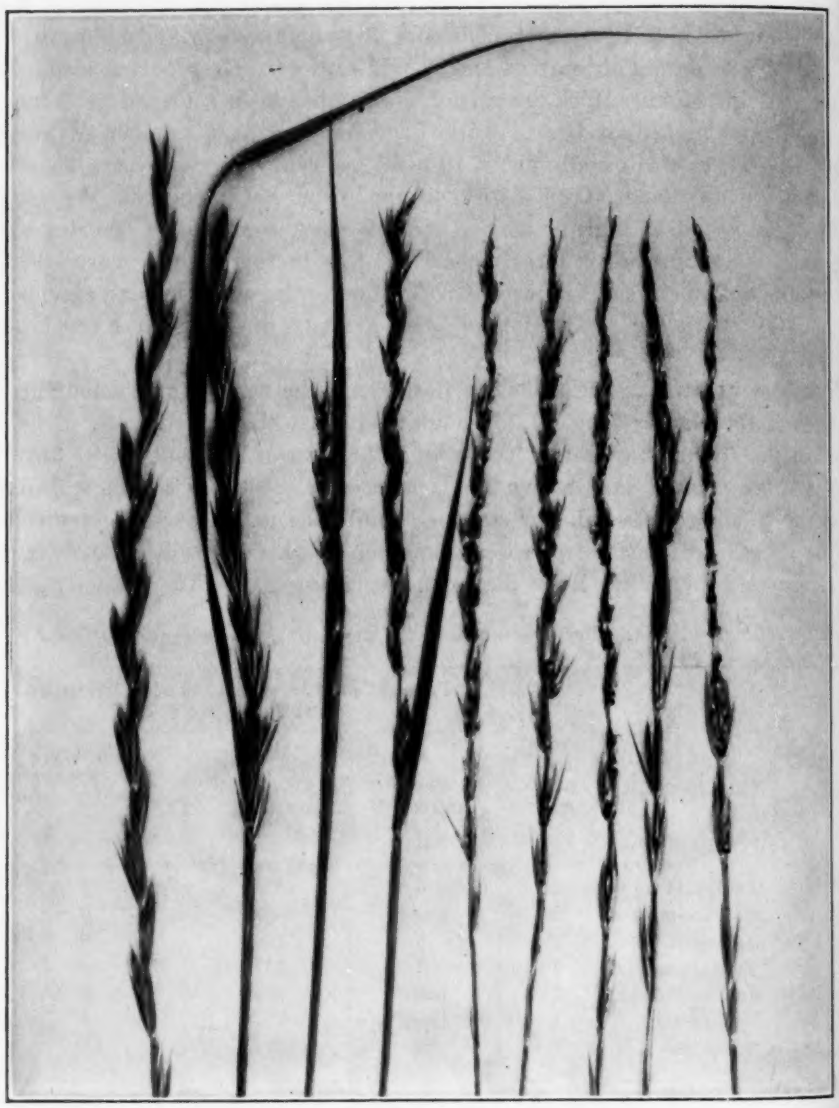

FIG. 1. Healthy and smutted heads of western rye grass.

smut. The experiments were not extensive; only one or two 16-foot rows were grown at each of two stations during four seasons. Seed artificially inoculated with spores was used. The results, however, were marked and consistent throughout, so there seems little doubt that ordinary formaldehyde treatment, 1–320, is effective. There was no evident injury to the seed from this treatment. A summary of the experiments is given in table 1.

Copper carbonate dust was tested in 1922 as a seed disinfectant for the control of this smut but was not effective, since 10 per cent of smut appeared in the treated rows. The checks showed 24.4 per cent of smut.

In 1920 seed of *Agropyron tenerum* was dusted with spores two years old from the same host. The dusted rows averaged 4 per cent of smut at Saskatoon and 3.75 per cent at Indian Head. The check rows were free from smut. Two 16-foot rows were used at Saskatoon and one at Indian Head. This indicates that the spores may retain their viability at least two years.

An experiment to determine the host range was made in 1924 at Saskatoon. Seed of various grasses was dusted with the spores of this smut from *Agropyron tenerum* and seeded in 16-foot rows. The results are given in table 2.

TABLE 2.—*Results of inoculating the seed of different species of Agropyron and Bromus with smut from Agropyron tenerum, 1924*

Row no.	Seed of	Notes	Per cent smut[a]	
			1924	1925
1	*Agropyron tenerum*	commercial seed	5.7	4.0
2	do	seed artificially smutted	47.9	23.2
3	do	do	50.8	20.6
4	*A. richardsoni*	do	14.6	4.1
5	*A. dasystachyum*	failed to head		6.0
6	*Bromus ciliatus*	3 smutted heads. Only a few plants headed		6.0
7	*B. latiglumis*	1 smutted plant. Only a few plants headed		.8

[a] As some of the grasses did not head in 1924, the rows were left until the next season, when all the grasses headed abundantly.

While it is suggested by the experiment that the smut on the Bromes came from the spores applied to the seed, yet, as no check rows were seeded, the experiment does not establish this.

Additional rows of seed treated with smut spores were seeded in Saskatoon in 1925. The results of this test are given in table 3.

Systematic position: The smut is closely related to *Ustilago bromivora*, the spores of which are slightly larger and the surface usually less finely verrucose. Measurements of 100 spores from *Agropyron tenerum* and *A. richardsoni* gave an average diameter of 9.23 and 9.26μ respec-

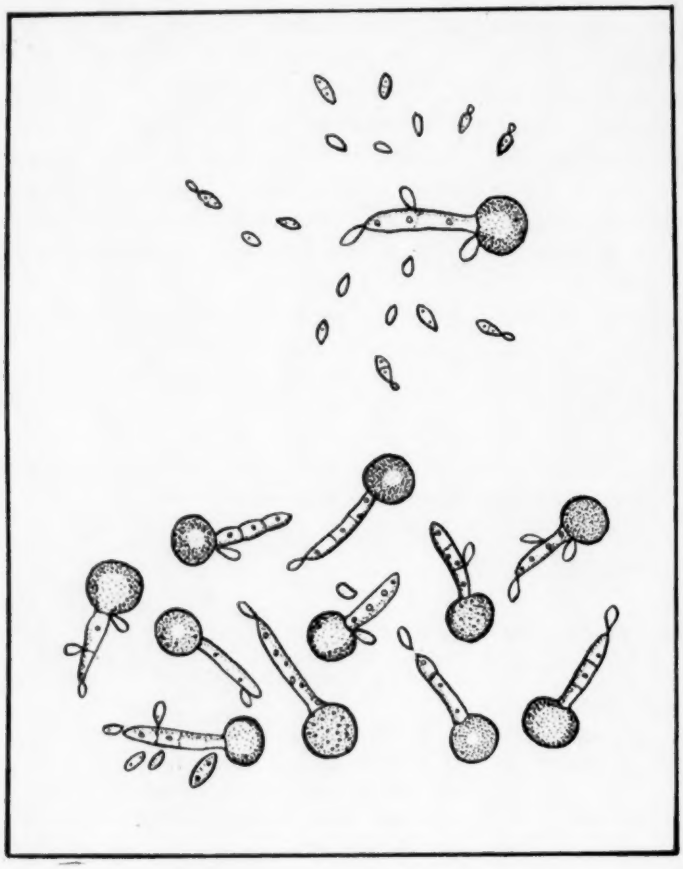

FIG. 2. Germination of spores of *Ustilago bromivora*.

tively, and the same number of spores of *Ustilago bromivora* from *Bromus ciliatus* and *B. tectorum* measured 9.94 and 9.53μ respectively. It seems best to regard this smut on Agropyrons as *Ustilago bromivora*. One field collection was made on *Agropyron richardsoni* at Saskatoon.

TABLE 3.—*Results of inoculating the seed of different species of Agropyron and Bromus in 1925*

Row no.	Seed of	Per cent smut
1	*Agropyron tenerum* (dusted with smut)	19.0
2	do (check)	0
3	*A. richardsoni* (dusted with smut)	16.8
4	do (check)	0
5	*A. dasystachyum* (did not head)	
6	do (do)	
7	*A. spicatum* (did not head)	
8	do (do)	
9	*Bromus ciliatus* (dusted with smut). A few plants headed.	0
10	*B. ciliatus* (check)	0
11	*B. porteri* (dusted with smut). A few plants headed.	0
12	do (check)	0

SUMMARY

A smut of *Agropyron tenerum* is common in the prairie provinces of Canada. It also attacks *A. richardsoni* and *A. dasystachyum*.

The smut closely resembles *Ustilago bromivora* and is assigned to that species.

The smut is controlled by the formaldehyde solution as used for cereals.

The experiments here described were carried out as part of the work of the Dominion Laboratory of Plant Pathology at the University of Saskatchewan. Acknowledgment is made of the assistance of the staff of the Laboratory in these experiments, and of the facilities afforded by the University for carrying on this work.

UNIVERSITY OF SASKATCHEWAN,
SASKATOON, SASK.

OBSERVATIONS ON INFECTIONS OF APPLE AND PRUNE ROOTS BY ARMILLARIA MELLEA VAHL

S. M. Zeller

Although the Armillaria rootrot is one of the oldest known plant diseases, the exact manner in which it enters a host plant is imperfectly known. It is usually taken for granted that spores of this fungus do not directly infect living hosts. Therefore, it must be a positive deduction that infection by the mycelium must take place directly by individual hyphae or by hyphae organized as rhizomorphs. Infection is not known to take place through roots which are too young to have developed a bark. In all reported observations, infection took place through rootstocks or larger roots, but there still seems to be question whether entrance is effected through healthy, uninjured bark, through wounds or through dead roots.

Hartig (4, 5) and Cieslar (3) experimented on a variety of dicotyledonous woody plants and arrived at about the same conclusions as those obtained by Wagner (7). Wagner planted 43 small trees of different sorts in garden soil which was infested by rhizomorphs of *Armillaria mellea*. Of these, 24 were intentionally wounded on the roots. Seven of the wounded trees became infected, while but one of the 19 unwounded was infected. Brefeld (2) found that, when freshly cut pieces of thick roots of Scotch pine were brought into close contact with rhizomorphs, the tips of the latter grew into the roots very quickly, both through the cut ends and through the undamaged bark. However, cut pieces of roots, especially coniferous roots, cannot be considered as healthy, and it is difficult to remove pieces of root without injury to the bark. It should be considered from his experiment not that rhizomorphs can force their way into the bark of a perfectly healthy root but that they can enter dead, or partially dead, bark.

Barss (1) suggested that "rhizomorphic strands . . . upon coming in contact with the root of the susceptible plant, may possibly bore their way into the healthy bark. It is believed by man, however, that the fungus gains its entrance, more often, if not exclusively, at points where the root or the crown of the tree has been injured."

Horne (6), who perhaps has observed Armillaria root rot of orchard trees in more of its various conditions and appearances than any other

American worker, observes that "when the tip of a rhizomorph comes to a healthy root the very small microscopic threads of which it is composed seem to loosen like the cut end of a rope and the individual threads penetrate into the bark and start a new infection." This comes the nearest to describing actual infection of healthy tissues that the writer has found reported.

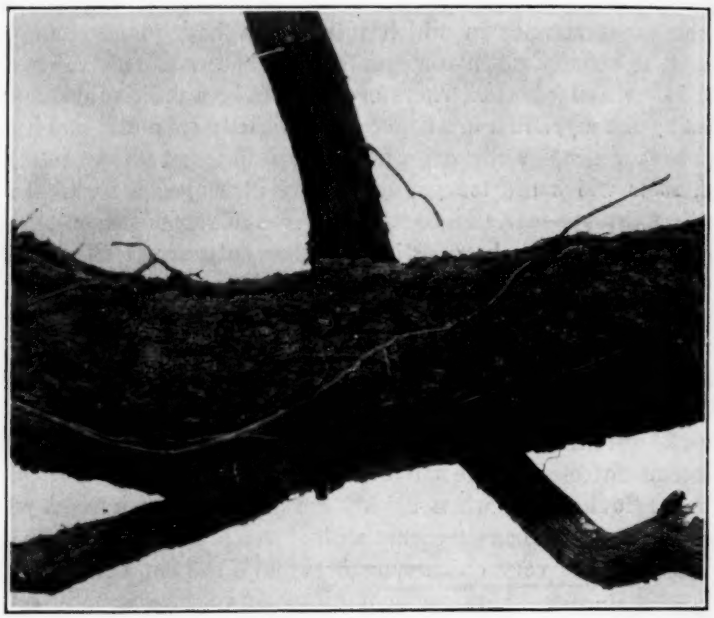

FIG. 1. A 3-year-old apple root which shows an oak (*Quercus garryana*) root thoroughly infected with *Armillaria mellea* lying in contact with the fork of the apple root as they were found *in situ*.

The Armillaria rootrot is a widespread, serious orchard disease in the Northwest, especially in that portion of the coast states west of the Cascade Mountains. The disease is particularly severe on prune trees and is rather serious in many apple orchards. In this region the strain of *Armillaria mellea* Vahl which grows on oak (*Quercus garryana*) is the one which causes destruction on orchard trees.

Since the fall of 1922 the writer has had several opportunities to observe infection of apple and prune roots by this oak-root fungus. Many examples of infection which were apparently through wounds have been found. These were near the collar of the tree not far from the ground line. However, after finding a few cases of infection of apple roots where there were

no signs of previous wounds, attention was attracted to the desirability of making further observations. Shortly, many more examples of this type of tissue invasion were found. One of the largest examples of this type of entrance to the host is illustrated in figures 1 and 2. Figure 1 shows a piece of oak root which was about 1½ inches in diameter and 18 inches long, lying across the fork of a branching apple root. These roots bore this exact relation to each other in the soil and were in contact. Figure 2 shows the same portion of the apple root as shown in figure 1 with the piece of oak root removed. The piece of oak root was thoroughly decayed by *Armillaria mellea* with the exception of a few sectors which were merely sufficient to identify the wood. The most interesting feature of the situation is the scurfy, cankered condition of the apple root where it was in contact with the diseased oak wood. Figure 3 illustrates a more developed stage of the same type of condition in a slightly older apple root. In this instance a diseased apple root crossed this apple root and made contact with it at the groove, designated by the circle. In the example illustrated in figure 1, infection had not gone farther than the inner parenchyma of the bark, while in the case illustrated by figure 3, infection had reached the cambium and had spread up and down the cambium from the point of penetration for a distance of about 2 cm. At the same time the fungus had penetrated the wood to a depth of about 2 mm. and up and down a total length of about 1.5 cm. The infected area of wood had the characteristic odor and color of Armillaria rot and was bounded by the characteristic dark line, while the inner bark was full of white mycelium bounded on the outer borders with a dark brown, fungous crust. The apple root illustrated in figure 1 was three years old when taken and that in figure 3 was four years old. There were no indications of wounds of any sort that might have been present in either case before the infections started. From the contour of the root illustrated in figure 3, it was not difficult to estimate that the two apple roots had been in contact for at least three years. This, however, led to no information as to the length of time necessary for the cambium to become infected, for there was no way to estimate the length of time the thoroughly diseased root had been diseased in that portion directly in contact with the root recently infected. Seventeen cases of this type of infection of apple roots have been observed in various stages of the scurfy bark. Five similar cases have been found on the roots of Italian prune trees.

Undoubtedly many who have had orchard experience with Armillaria rootrot have observed its toxicity to affected trees. Whether this toxicity is due to the presence of the fungus itself or to the products of its metabolic activity in the wood is not known. Especially where this rot has been found affecting prune trees, the writer has seen many cases of the toxicity referred to. If a tree has only one root affected, with infection extending well up

toward the collar, at first only those branches immediately above the affected root will yellow and die, although the whole tree may finally die. It is not the loss of the root which has affected the branches above, for, when such a root is pruned, the branches of the tree apparently go unharmed. It seems that the death of branches in such cases must be brought about by the toxicity of the product of the organism working in the wood.

The writer believes that the type of infection mentioned above has its start through healthy bark which has been acted on by toxic substances given off by tissues decayed by *Armillaria mellea*. The very first indication of this toxic influence on the bark is the appearance of a shallow, browned

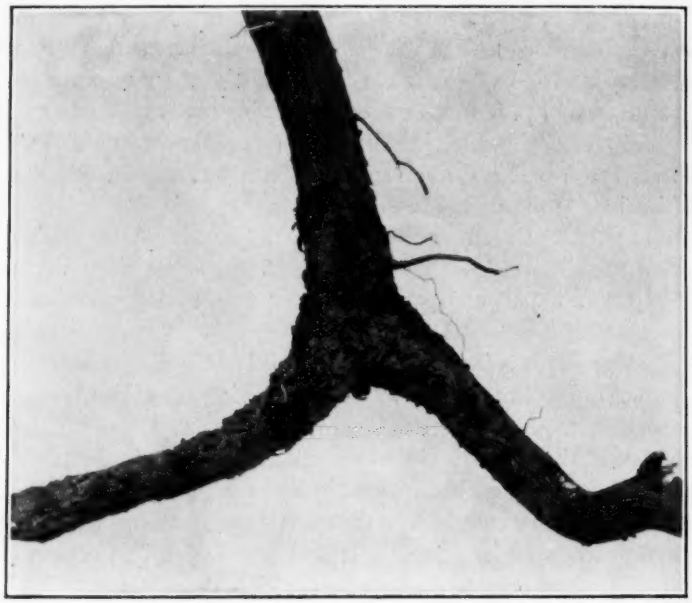

FIG. 2. The same portion of the apple root shown in figure 1 with the oak root removed. Notice the scabby, cankered appearance of the apple bark where it was in contact with the Armillaria-decayed oak root.

spot in the outer parenchyma of the bark of the root just around and under the lenticels. These are at first of a blistery, edematous consistency and later dry down and flake. Soon several such blisters may appear and flake. When dried, the thin circular flakes curl up at the edges, the appearance of the bark reminding one of the rough bark produced by pear scab infections on young twigs. It resembles a type of so-called "burning" which may take place when organic débris is piled too closely to young bark. These spots coalesce until one soon finds a superficial condition like that illustrated in figure 2. Evidently, this condition is extended deeper very

slowly, new layers of dead flakes being sloughed off as new plate-like cork layers are formed in the bark parenchyma. This continues until a cankered condition appears as illustrated in figure 3, when the mycelium of the fungus is able to pass beyond the inner parenchyma of the bark to the cambium. In the earlier stages of the flaking off of the outer parenchyma, no mycelium of the fungus was found in the affected spots until at least two or more plates of cork had been sloughed.

This type of infection is apparently a very slow process, but the wound through which the fungus enters is an indirect result of the presence of the organism or its metabolic products. No attempt has been made to deter-

FIG. 3. A 4-year-old apple root showing the cankered condition produced by an Armillaria-decayed apple root which crossed in contact with it in the position of the circle. In this case the Armillaria infection had penetrated to the cambium.

mine the nature of the products which are toxic to the bark tissues.

A few observations have been made in connection with another type of infection of the roots of prune trees. A note concerning the place of entrance and the writer's theory as to the mode of entrance might be an aid to others doing similar field observation. It has been found that parent roots are frequently infected around newly formed lateral roots. Cases have been found where only the parenchyma of the parent root immediately surrounding a new lateral in its first year's growth was invaded by the mycelium of *Armillaria mellea*, and more advanced stages where this has reached the cambium have been observed. The writer has assumed that the rupture of the bark parenchyma by the young lateral root as it pushes out through the bark has provided an entrance in such cases where a vegetative portion of the fungus chanced to be near at the time of rupture. The several instances of this kind have shown nothing to disprove the assumption, although actual penetration has not been followed.

SUMMARY

1. Rootrot, caused by *Armillaria mellea* Vahl, is a widespread, destructive orchard disease in the Northwest, especially in that portion of the coast states west of the Cascade Mountains.
2. Infection of the roots may take place in at least three ways:
   (a) Through wounds. Examples of this type of infection are common.
   (b) At points of contact of diseased and healthy roots. Seventeen cases of this type of infection of apple and five similar cases of prune infection have been observed.
   (c) At point of emergence of lateral roots, apparently through the rupture of the bark parenchyma by the young lateral root as it pushes out through the bark.
3. When infection occurs at the point of contact of diseased and healthy roots, it probably starts through healthy bark which has been acted upon by a toxic substance given off by tissues decayed by the fungus.

OREGON EXPERIMENT STATION,
CORVALLIS, OREGON

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A SPOT-ROT OF APPLES IN STORAGE CAUSED BY BOTRYTIS[1]

F. D. Heald and Roderick Sprague

INTRODUCTION

A storage rot of apples caused by *Botrytis cinerea* has long been known in the Northwest. Briefly, it is a light brown, moderately soft rot which, under moist conditions, develops grey conidial tufts that completely cover the surface of the decayed fruit.

During the fall of 1921 a striking departure from these ordinary symptoms was noticed. On a single Rome Beauty apple from common storage, showing a pale brown lesion, nearly every lenticel in the rotted area was surrounded by a darker brown ring. Except for these peculiar reddish-brown spots which had not heretofore been associated with the rot, the appearance of the host and fungus was characteristic of *Botrytis cinerea*. Microscopic examinations and isolation cultures gave what appeared to be typical *Botrytis cinerea*, but at that time no further study was made of the rot.[2]

In early November, 1923, Rome Beauty apples affected with the spot-rot were obtained from one cellar, and a few days later Delicious and Wagener apples from another cellar at Pullman. It has since been observed in common storage Romes at Spokane. From the time of the first collection of apples in November until the last of February, the spot-rot of apple could be found in the storage cellars around Pullman. Sufficent material was on hand during the season for a more detailed study of the spotting and its cause.

CHARACTERISTICS OF THE SPOT-ROT

Botrytis rot of apples is generally light brown in color. The decayed areas frequently have at first a pale, translucent, watery appearance which soon changes to a duller brown. The striking feature of the rot was the evident darker spots which always centered around the lenticels. They are brownish-red rings of about 2–3 mm. diameter, each showing a pale or

[1] Published with the approval of the Director of the Washington Agricultural Experiment Station as Scientific Paper No. 133, College of Agriculture and Experiment Station, Pullman, Washington.

[2] Heald, F. D., and Dana, B. F. Notes on Washington plant diseases. I. Botrytis diseases. Trans. Am. Mic. Soc. **43**: 136–144. 1924.

whitish area in the center. This lighter region at the center and a paler zone on the outside cause the rings to show up in a striking fashion. The spots are not numerous, averaging 4–20 to the square inch, and give to the surface an appearance similar to that of a polka-dot fabric (Fig. 1).

After being left in damp chambers in the warm laboratory a few days, the spots lose their definiteness and spread out as blotches or darker discolorations on the surface of the fruit. They do not lose their identity entirely, however, as the white area in the center of the spot remains to mark the place where the spot originated. Conidial tufts soon begin to push through the surface, and in a few days the fruit is a mass of grey mold.

ISOLATIONS

Isolations were made from partly decayed and spotted fruits, previous to the appearance of any external conidiophores, by removing bits of tissue from the advancing edge of the rot with a flamed scalpel and planting them on poured plates. Three per cent dextrose agar + 10 was used. On this medium a flat spreading growth developed, which gave rise in a few days to the grey, fluffy patches of fruiting *Botrytis*. At the same time the cultures showed a peculiarity in the nature of a red coloring of the substratum which was not typical of *Botrytis cinerea* as commonly isolated from apples in this region. Microscopic examination of the cultures showed typical Botrytis spores and conidiophores, agreeing in spore measurements fairly closely with *Botrytis cinerea* ($4.6 - 7.5 \times 7.5 - 13.1\ \mu$).

INOCULATIONS

From the fact that the isolated fungus acted peculiarly on media, and because the symptoms on the host were different from the usual Botrytis rot, inoculations were made to determine whether the common *Botrytis* or any of its strains would cause the spot-rot under laboratory conditions. Before carrying on inoculation experiments, a known pure culture of *Botrytis* was obtained by making a streak plate from spores from tufts on the surface of a Botrytis-rotted fruit. The two following cultures were thus available for use: (a) the "unknown" culture obtained from mycelial transfers from a spotted apple, (b) pure *Botrytis* from spores. The pure *Botrytis* culture did not color the substratum. Rome Beauty and Jonathan apples were inoculated with these two cultures. The inoculations were made by cutting rectangular flaps in the apple with a flamed scalpel and inserting a small mass of mycelium under each flap. Uninoculated checks were kept. The different lots of apples were placed in sterilized damp chambers and kept in the laboratory at room temperature.

The development of the rot was observed daily over a period of two weeks. Spotting occurred along the advancing edge on apples inoculated

with the "unknown" cultures and also faintly on apples inoculated with the pure culture of *Botrytis*. At the temperature at which the apples were held, the experiment was inconclusive.

Next, inoculations were made to show whether the culture of known *Botrytis* would cause spotting simliar to that caused by the original isolations if the specimens were incubated at a lower temperature. Since Jonathan apples had not proved satisfactory, Rome Beauty apples were used exclusively in the following inoculations with:

(a) the original culture from spotted Rome apple;
(b) known *Botrytis* from spores;
(c) rotted tissue direct from spotted Delicious apple.

These were made in duplicate and placed in moist chambers. One set was left in the laboratory at room temperature, and the other was placed

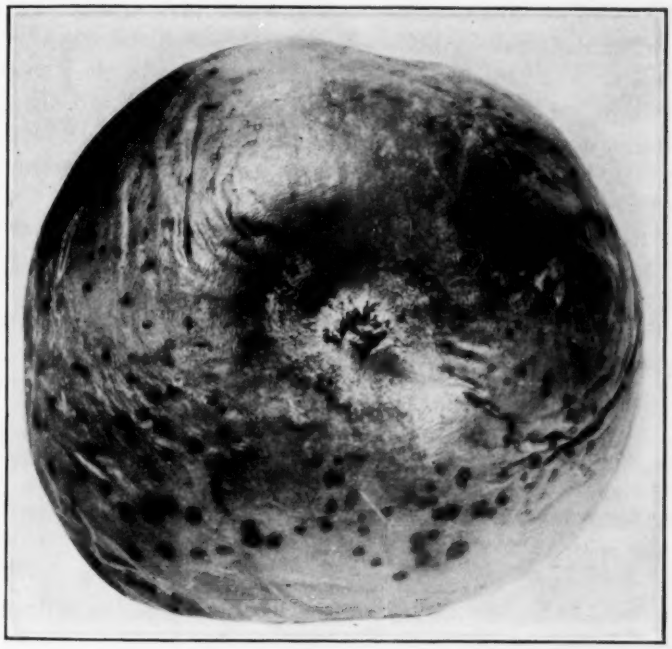

FIG. 1. Rome Beauty apple completely rotted by *Botrytis cinerea*.

in a cool storage cellar at 35°–45° F. While these inoculations were incubating, effort was made to find out something concerning the coloring of the media. The original culture had retained part of its color at least, through four separate transfers. The known Botrytis culture showed no

coloring, while an isolation from a Delicious apple showed a faint amount of color, and several other spore-streak plates varied in their coloring. The different strains seemed to retain their media-coloring characteristics through numerous transfers in only faintly decreasing intensity.

Daily observations were made on the development of the lesions on the inoculated apples. Spotting appeared along the advancing edge of the rot in all cases during the first few days.

The spotting of the apples kept in the laboratory soon spread out into vague, irregular blotches and became indistinct or disappeared, but could, however, be noted to a slight extent along the advancing edge. There were no differences in any of the inoculated apples kept in the laboratory, either in spotting or in rate of decay. At the end of 22 days the apples in the laboratory were entirely rotted and covered with a grey mass of conidal tufts.

When the apples in the cellar were brought back to the laboratory at the end of 22 days they were one-half to three-fourths rotted. The decayed areas were lighter in color and more translucent than those on the apples held in the laboratory, and were covered with the characteristic spots, even the older spots retaining the sharply defined ring form. As in the laboratory specimens, there were no differences in the various inoculations, all three cultures producing the same kind of spotting.

Re-isolations gave typical *Botrytis* in all cases. The red coloration of the medium was constant, appearing where it had been originally and not appearing where it had been absent. The persistent red color in some cultures of *Botrytis* and its absence in others seems to be characteristic of different cultural strains of the fungus.

SUMMARY

1. The spot-rot of apples is caused by a species of *Botrytis,* probably *B. cinerea.*

2. The Botrytis rot develops best at relatively high temperatures but without the spotting.

3. The spotting of the apple depends on development of the rot at low temperatures. At higher temperatures the spots become indistinct blotches or fade out entirely.

4. The development of the red coloration of the cultures is peculiar to certain strains or isolations.

DEPARTMENT OF PLANT PATHOLOGY,
STATE COLLEGE OF WASHINGTON,
PULLMAN, WASHINGTON.

BOOK REVIEW

Fungous Diseases of Fruit-Trees in New Zealand and Their Remedial Treatment. By G. H. Cunningham, B.Sc. Spray formulae in collaboration with the Director, Assistant Director, and Orchard Instructors, Horticulture Division, Department of Agriculture. 382 pages, 177 figures. Published under the authority of the New Zealand Fruit-Growers' Federation, Ltd., by The Brett Printing and Publishing Company, Ltd., Auckland. 1925.

This book was written to meet the needs of fruit growers for information relating to diseases which affect commercial orchards of New Zealand. To this end, the author has sought simplicity of treatment, and a scope and arrangement of material "in accordance with suggestions from the orchardists themselves."

The first or "general" section of the book (99 pages) is devoted to an elementary consideration of the geography and climate of New Zealand, botany of the fruit tree, wounds and their treatment, fungi, bacteria, diseases of plants, and remedial treatments. The second or "special" section (249 pages) deals with specific diseases. These are treated in three divisions: I. pome fruit (apple, medlar, pear, and quince) diseases; II. stone fruit (almond, apricot, cherry, nectarine, peach, and plum) diseases; and III. citrus fruit (grapefruit, citron, lime, lemon, orange, and pomelo) diseases. In each division the diseases are subdivided into three groups, (a) "fungous," (b) "bacterial," and (c) "physiological." At the beginning of each major division are a chart showing the diseases which affect each host and an artificial key for the identification of diseases by symptoms. Each disease is treated in relation to the host group which it most seriously affects. The treatment of each of the more important diseases ordinarily includes consideration of names, hosts, geographic distribution, "appearance and effect on the hosts," life history of the causal organism, and control measures. Following the treatment of each disease are references to citations which are assembled in a bibliography of 337 titles. Technical words are explained in a glossary.

The book is well printed on good paper. The illustrations are numerous and, to an unusual extent, original. Many of the photographs are of excellent quality, although a few are poor. The drawings are semi-diagrammatic. The illustrations are well reproduced. In most cases, however, they would serve their purposes equally well and add to the attractiveness of the work if somewhat reduced in size.

The author is to be congratulated upon the successful way in which he has accomplished a very difficult task. He has combined the simplicity of treatment requisite to the purposes of the book with scientific soundness and accuracy. From the point of view of the fruit growers for whom it was written, the book should be very satisfactory. It should be realized, however, that in a single volume of this length and scope it is impossible to give a full discussion of the practical problems presented by each disease treated. For this more detailed or extended information, it will be necessary to seek special advice or refer to special literature. From the point of view of the plant pathologist, the book presents a welcome and valuable account of the fruit dis-

ease problems of New Zealand and the methods which are being used to meet them. Its limitations are, for the most part, those imposed by its scope and purposes. The treatment of diseases which affect several plants in relation to host groups, rather than individual host plants, for example, precludes giving as much attention as would be desirable to problems which vary with hosts. In the treatment of symptoms and the preparation of keys to identification by symptoms, the author appears to attach more weight to the constancy of symptoms and the fixity of their relations to specific causes than would the present writer. The book shows evidence of much care in preparation and contains few errors in typography or transcription.

The wisdom of the author in seeking the assistance of individuals and organizations in position to contribute to his enterprise and the liberal spirit of cooperation with which they responded merit special note and commendation. This work does credit both to the scientific leadership and the intelligent initiative of the fruit growers of New Zealand.

G. W. KEITT